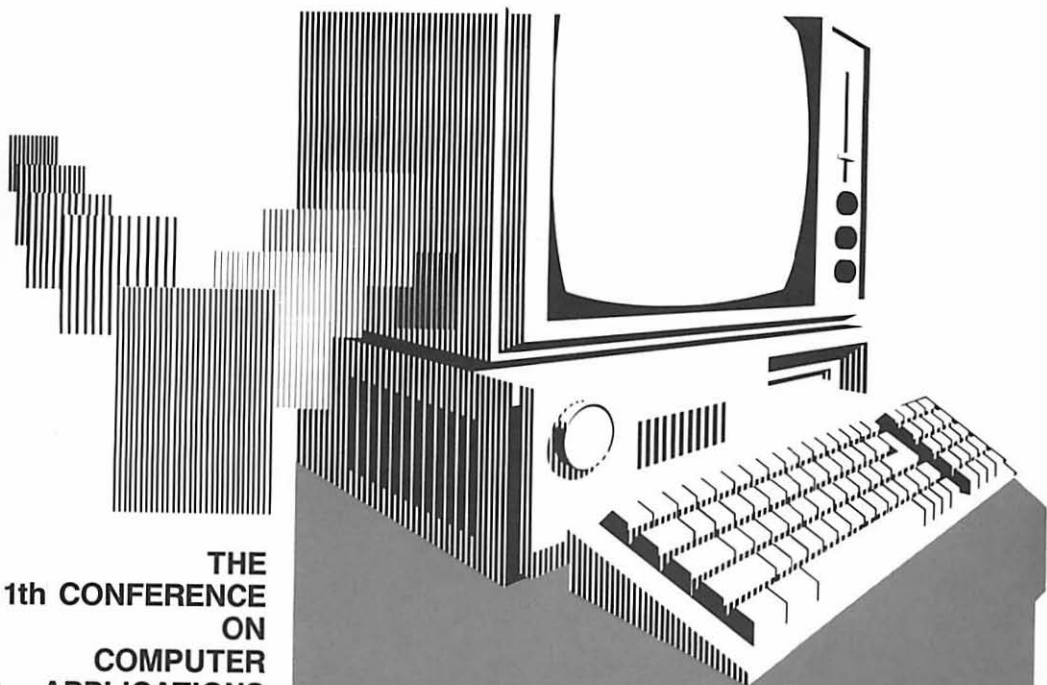




THE
11th CONFERENCE
ON
COMPUTER
APPLICATIONS
IN
RADIOLOGY
AND
6th CONFERENCE
ON
COMPUTER
ASSISTED
RADIOLOGY

Jointly Sponsored By
The Johns Hopkins
Medical Institutions
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Medical Systems

SCAR 92 SYMPOSIUM FOR COMPUTER ASSISTED RADIOLOGY

BALTIMORE, MARYLAND
JUNE 14-17, 1992

SCAR 92

COMPUTER APPLICATIONS TO ASSIST RADIOLOGY

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INTRODUCTION

Background

This Symposium will be the 11th Conference on Computer Applications in Radiology, a series that began in 1964. The American College of Radiology (ACR) sponsored the first eight Conferences which emphasized developments in medical imaging, particularly those related to advances in computer technology that affected information systems, image management and communication networks. Because of financial concerns, the ACR turned over the responsibility for supporting the Conference to the Radiology Information System Consortium (RISC) which organized the 9th Conference, held in Hilton Head in June of 1988. The ACR co-sponsored that meeting and has continued to co-sponsor the Symposia through 1992. The early meetings emphasized the efforts of workers in the field to adapt computer technology for radiology information systems and computer assisted diagnosis. At recent meetings, picture archiving and communication systems (PACS) and image processing have become the principal subject matter of many presentations.

The Society for Computer Applications in Radiology (SCAR) was formed several years ago to provide a forum for individuals interested in the exchange of scientific information concerning the use of computers in radiology. SCAR was sponsored by RISC, which requires institutional membership, to establish an organization for individuals interested in applying computer technology to medical imaging. The sponsorship of the Symposium by SCAR has been supplemented by an affiliation with Computer Assisted Radiology (CAR), an organization that has conducted four successful symposia in Berlin, held every other year in the odd numbered years. Professor Heinz Lemke of the Technical University of Berlin has organized each of the CAR meetings and has made major contributions to the planning of S/CAR '90 and '92. The CAR staff has encouraged a substantial number of European leaders to participate in the program, and many registrants are expected from Europe as a result of the publicity.

Participation from Japan includes both academic radiology and industry. Dr. Atsuko Heshiki who trained at Johns Hopkins and is now the Chairperson of Radiology at the Saltama Medical School, is coordinating participation and attendance by colleagues in Japan. Dr. Heshiki has been a major contributor to several IMAC Conferences, and is a recognized authority in the transmission of medical images for primary diagnosis in Japan.

The Program

The general program includes tutorials, scientific presentations, technical exhibits, poster sessions and demonstrations of computer applications in medical imaging, both at the OMNI Hotel and the host institutions, namely, The Johns Hopkins Medical Institutions and the University of Maryland Medical Systems.

Tutorials

The tutorials cover a basic introduction to digital imaging, the key elements of preparing the specifications for a request for proposals (RFP) by companies who market PACS systems, an update on the ACR/NEMA Standard and an in-depth discussion of the controversial topic of government regulation of medical software. The presenters are well known experts in their respective fields and have current practical information on the several topics.

Picture Archiving and Communications Systems

A major subject at the Symposium is PACS, often referred to as Image Management Systems, for which 18 papers were accepted, covering a wide range of topics from the philosophical justification for such systems to the practical problems encountered by several hospitals when attempting to install PACS components. The subject matter includes image capture, data compression, transmission of images and related data, storage media and display options.

Image Processing

There were a large number of abstracts submitted on the subject of image processing which has begun to show its benefits in clinical practice. Twenty papers related to various image processing techniques have been included in the program with emphasis on their applicability to improving the delivery of diagnostic imaging service to the patient's primary physician for care and treatment. Of particular interest are the clinical applications that routinely utilize three dimensional conversions of magnetic resonance and computed tomography examinations for pre- and post-surgical evaluations.

Expert Systems and Teaching

The proliferation of personal computers has made it possible to bring the power of this technology to a large number of workers in the field, including practicing radiologists who wish to have access to large bodies of information that may be pertinent to a specific diagnostic problem. Expert systems or "artificial intelligence" are beginning to influence the diagnostic process at many leading institutions and several papers deal with this application. There will be several presentations demonstrating the teaching capabilities of computers, particularly interactive programs that emphasize the need for presenting high quality diagnostic images as part of the educational process.

Information Management and Teleradiology

While many traditional radiology information system problems remain to be addressed through advances in computer technology, the changing emphasis towards image management is becoming apparent from the papers on this subject. Teleradiology, which may be considered a subset of image management systems design, has achieved a major role as improvements in computer technology and telecommunications have been achieved. Papers in these sessions range from basic considerations of communication in medicine to the technical limits of transmitting images.

Computed Radiology and Image Displays

The potential generation of high quality "digital radiographs" through the use of stimuable phosphor technology is the subject of several papers with a view towards specific applications with diagnostic radiology practice. These "filmless" techniques can be combined with appropriate displays to interpret and review images at several locations within hospitals. These subjects will be addressed by authors in this session who see these developments as major advances in the delivery of care. There will also be a review of the functional requirements of film digitizers that can convert hard copy analog images to a digital form compatible with hospital networks.

Research

The role of computer technology in radiology and radiological science has been critical to advances in diagnostic modalities and to understanding the potential adverse effects of exposure to ionizing radiation. In this session, papers will be presented on an "object-oriented" approach

to medical image data, the use of CT data to model conventional film radiography, and an evaluation of phantom images used for mammographic accreditation. This session will also include experience with a PC database on MR cases and the clinical value of ultrasound in managing heart transplant patients.

Government Agency Sessions

There will be three sessions on current projects related to advances in medical imaging that are supported by government agencies. Physicians and scientists from the Department of Veterans Affairs and the Public Health Service will present recent developments in information systems and image management networks sponsored by the agencies. There will also be papers on computer assisted radiology research funding, automated data and data standards, and the "Visible Human Project" at the National Library of Medicine. A major development, the installation of a PAC System at Madigan Army Hospital will be described by the senior staff of the Medical Diagnostic Image Support (MDIS) Project. This will include a discussion of the specification process, the selection of contractors and the early experience with the system.

Conclusion

No symposium would be complete without an open discussion of "what does all this mean?" The closing session is expected to be a provocative exchange of differing opinions on the future of radiology and medical imaging in view of its increasing dependence on new technology. Leading authorities from academia, industry and governmental health care agencies will discuss the issues facing physicians, administrators and politicians who influence the direction of health care policy. This session promises to be a memorable occasion for all who attend.

Joseph N. Gitlin, D.P.H.

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Future Symposia

The following meetings are already well along in the planning stages. The CAR meetings will be held out of the U.S. every other year to alternate with the S/CAR meetings to be held in the U.S. Please mark your calendars for the following:

CAR '93 – Computer Assisted Radiology

June 24-26, 1993

Berlin, Germany

S/CAR '94 – Symposium for Computer Assisted Radiology

June, 1994

The Bowman Gray School of Medicine

Winston-Salem, North Carolina, USA

CAR '95 – Computer Assisted Radiology

In conjunction with the celebration

of the 100th anniversary of Roentgen's discovery

Berlin, Germany

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Tutorials

Digital Image Acquisition and Display: A Tutorial

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I. Introduction

The purpose of this tutorial is to give an overview of the physics of image acquisition for all modalities and the technology of digital image manipulation, management and display. It is in two parts: an overview of imaging physics and an overview of digital imaging technology with emphasis on image processing.

II. X-ray Imaging Modalities

The earliest digital X-ray imaging modality was computed tomography (CT). CT imaging uses a beam of X-rays to scan the brain in planes parallel to the longitudinal axis of the body from a large number of different angles and a computer to reconstruct a map of brain density. As with most X-ray imaging modalities, delineation of cross-sectional anatomy was achieved but not tissue characterization.

Digital subtraction angiography (DSA) digitizes sequences of fluoroscopic video images while contrast material is being injected into a blood vessel. The average of several frames taken before contrast is subtracted from the images taken during contrast injection. High-contrast viewing allows visualization of vascular anatomy.

Computed radiography (CR) images X-ray intensity patterns on phosphor screens similar to X-ray intensifying screens. X-rays incident on the phosphor creates a pattern of trapped charge which creates a pattern of visible light when illuminated with a scanning laser beam. The light pattern is digitized and stored for further display.

III. Nuclear Magnetic Resonance Imaging

In magnetic resonance imaging (MRI) the nuclei of specific isotopes in the body are stimulated with radio frequency (RF) energy to undergo coherent precession. They then emit RF energy at a frequency characteristic of the particular nucleus being imaged. The most commonly imaged nucleus is hydrogen. Since hydrogen is omnipresent in the body, these images delineate anatomy rather than pathology.

More recent developments have greatly improved the anatomical imaging capability of MRI and begun to provide functional imaging as well. MR angiography uses sophisticated RF pulse sequences and manipulation of the magnetic field gradient

in the imager to image flowing blood and suppress the images of stationary anatomy. This and other techniques such as spectroscopy are undergoing intense development.

IV. Ultrasound and Nuclear Medicine

Although nuclear medicine (NM) and ultrasound (US) were available in digital form earlier than most X-ray modalities and far earlier than MRI, their limited spatial resolution has kept them from dominating radiological imaging. NM images are captured by digitizing the location of each radioisotope event detected by a gamma camera. US images are digitized by recording the angle of the transducer when it emits a pulse of energy and the time of arrival of echoes from tissue interfaces.

V. Digital Storage and Display

Digital image storage is a simple matter of mapping the characteristics of an image to a computer memory. Digital images may be stored in random access memory (RAM) for high speed access or on disk or tape for higher capacity albeit slower access. Archival storage of images is typically done on optical disk which offers slower access than magnetic disks but better archival quality, much higher capacity and lower cost per bit. A mixture of different storage types is the norm for an image management system.

Display of digital medical images makes use of computer graphics technology developed for other purposes. The usual display medium is a cathode-ray tube (CRT) display or video display. The contents of a dedicated RAM memory buffer are converted to a video signal which in turn controls the brightness on the CRT screen. This controls the brightness of the display screen, which is usually monochrome rather than color.

VI. Digital Image Manipulation

Image processing is the manipulation of image information during or after acquisition to improve visualization of important clinical detail. It requires a complex interaction of system design, hardware and software to achieve its goals.

Image processing ranges from simple brightness and contrast control to more advanced types of manipulation such as image filtering for improved visualization, image compression for improved speed of transmission and lower storage requirements and image reformatting for visualization of volume (3D) images.

A study of the three applications cited above shows how clinical goals and available technology combine to define the limits of feasibility. The final role of image processing in radiology will be defined by the interplay between the basic physics of the imaging processes in each modality and the development of imaging technology, both hardware and software.

VII. Image Management Networks

A wide variety of networking technologies are available, including Ethernet, FDDI, OSI and others. The choice of network technology is dictated by considerations of volume, speed and cost. The ACR-NEMA network standard is currently being revised to allow maximum flexibility in network design.

Purchasing PACS, A Practical Tutorial

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Although there have been numerous papers describing the design and performance characteristics of a picture archiving and communications system (PACS), very little has been written about the practical considerations involved in the process of purchasing a PACS. The new 324 bed Baltimore VA medical center, which is expected to open November 8, 1992 and Hammersmith Hospital in the United Kingdom have purchased PACS equipment and are committed to full operation in a digital, soft-copy environment.

The first and most important step in the purchase of a system is to define the term, PACS. The literature uses this term for a wide variety of different types of equipment in a large number of different configurations with many different functions.

The next and perhaps equally difficult assessment, given the current state of technology, is whether or not the PACS will actually result in an improvement over a conventional radiology department. Since there are currently no other soft-copy radiology departments, this is perhaps the most difficult decision that one must make. The decision depends on a multitude of factors including available space and funding, acceptance by the radiology and clinical staff, hospital support, assessment of the available technology, current volume of studies, and current staffing of the radiology department.

One of the most difficult problems is that the cycle from the initial planning of the PACS to its purchase and delivery may be at least two and as many as five or more years. The extraordinarily rapid advances in technology have resulted in major improvements in network speed, monitors, storage devices, and database and display software.

Obtaining sufficient funding for the PACS will present a difficult challenge in any medical facility. However, it will also be difficult to predict the cost of the final system at the beginning of the project because of the changes in price that occur with new developments in technology and changing expectations for the performance and functionality of the system.

Site visits to other facilities that have some or all of the components of the PACS are extremely helpful to provide insight into the actual operation and integration of the components. These visits may provide helpful information about installation, reliability, and service.

In the case of the Baltimore VA Medical Center, in addition to the PACS, other new equipment was purchased for radiology and nuclear medicine. This provided us with the opportunity to obtain equipment which would facilitate soft-copy operation. For example, a sixteen inch image intensifier was purchased as part of the angiography equipment to allow virtually all angiograms to be obtained without the use of film. Additionally, the fluoroscopy rooms were purchased with digital "spot" imaging capability, again to allow image acquisition digitally and to facilitate image transfer to the PACS. All of our digital modalities such as CT, MRI, ultrasound, and nuclear medicine were purchased with ACR-NEMA interfaces.

The next step in the purchase of a PACS is the formulation of a detailed technical proposal for the system. This proposal should include references to the following:

- A. Installation schedule
- B. Modalities to be interfaced to the system and expected volume
- C. Detailed descriptions of the subsystems
- D. Definition of system "downtime" and "uptime" requirements
- E. Provisions for component additions and deletions
- F. Personnel requirements
- G. Service and Preventative Maintenance
- H. Training

Prior to the purchase of the PACS, the vendor should be required to submit to a "benchmark" test of the full system or its components. At the benchmark test, all of the operations of the system and the specific times required for those operations should be carefully observed. The benchmark testing should provide the basis for the final acceptance testing of the system. It is important that a specific acceptance testing protocol be developed and agreed upon by the vendor and by the customer. This document should be derived from the PACS proposal and from the benchmark testing and will serve as an objective statement of specific expectations for the system at the time of delivery.

The purchase of a large-scale PACS is a very complex process which requires a clear definition of the precise objectives of the project, the requirements of the hospital, and the current technology. The relatively large time interval between initial planning of the system and system delivery coupled with the rapid changes in technology make the purchase of a PACS a challenging prospect.

The ACR-NEMA DICOM Standard: Information Model, Commands, and Network Protocols

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INTRODUCTION

Version 1 of the ACR-NEMA Digital Imaging and Communications Standard, published in 1985, established a reasonable common ground for users and vendors. The original Standard specifies a hardware interface, a data dictionary, and a set of commands. Field tests of Version 1 led to refinements which resulted in the publication of Version 2 of the ACR-NEMA standard being published in 1988. Ten years following the formation of the ACR-NEMA committee, devices conforming to Version 2 of the Standard are widely available.

The incorporation of an object-oriented data model and the addition of support for ISO Standard communications substantially broaden the scope of Version 3: DICOM (Digital Imaging and Communications in Medicine). DICOM is extendible to support multi-specialty medical imaging with the associated text and graphics. The draft document of the Standard is composed of nine parts. Parts 1 and 8 have been released for comment, prior to balloting by NEMA. The remaining seven parts are scheduled to be circulated for comment in December, 1992. The modular design of DICOM facilitates editing and future enhancements.

NETWORK CONNECTIVITY WITH DICOM

The DICOM standard, represents a major conceptual departure from the limited point-to-point communications goal of Versions 1 and 2 of the ACR-NEMA Standard. While maintaining compatibility with the 50-pin physical connector and the signaling protocol of the original Standard, DICOM specifies means of alternative connections which simplify multi-point networking. The DICOM standard simplifies network connections by defining an *Upper Layer* Communication Software Service which supports two widely-used communications standards: TCP-IP (Transmission Control Protocol - Internet Protocol) and ISO OSI (International Standards Organization, Open Systems Interconnection) protocols.

FOLDERS AND FILE LINKING:

The draft Version 3 of the DICOM Standard incorporates a mechanism for linking related images to a single identification header during transport. Working Group VI of the ACR-NEMA Committee is considering the final form of the message folder structure to eliminate repetition of identical data elements. The reduction of redundancy will be significant, particularly in nuclear medicine.

INFORMATION MODELING: OBJECT-ORIENTED ANALYSIS

In the process of developing the DICOM standard, the ACR and NEMA jointly have taken the difficult first steps toward the complete reorganization of the information model on which Versions 1 and 2 of the ACR-NEMA standard were based. An object-oriented information model reduces redundancy and ambiguity by requiring that information objects be defined only in terms of their most fundamental and unchanging qualities and/or values -- their lowest common denominators. Related but not identical types of entities are grouped into information object classes. An instance of an object class is an individual member of the class type. A unique identifier value (UID) is assigned to each class of information object and to each instance of an object class.

DICOM COMMANDS

DICOM supports *composite commands* for compatibility with Versions 1 and 2. A new set of *normalized commands* also are available for handling the information objects defined by DICOM. These CMIS (Common Management Information Services - ISO 9595 and 9596) commands have an efficient and understandable structure which can streamline message exchange and database inquiries.

CONFORMANCE AND INTEROPERABILITY

Missing from the early Versions of the ACR-NEMA standard is a rigorous treatment of the issue of conformance. Thus, ambiguity has existed among various interpretations of the earlier Versions. Interoperation implies that connected devices not only interchange information (supportable through Versions 1 and 2), but instructions on what to do with, and messages about what has been done to, the information. The defined information objects and commands of Version 3 together will support communication *and* interoperation of equipment connected using one of the DICOM network specifications. DICOM approaches the issues of conformance and interoperability through the mechanism of the *service class*. A service class is a set of services provided by a service class provider (SCP) to a service class user (SCU) over an association. The detailed specification of the service class is called a service class specification. It defines, in abstract terms, the service supported and the required and optional attributes of all commands and information objects exchanged between the SCP and SCU in supporting the service. The service class specification does not define how the service class is to be implemented. An advantage of the service class approach is that it forms the nucleus of the conformance claim. Such a claim is structured according to Part 2 of DICOM, and will allow a manufacturer to detail exactly what service classes are supported, and which, if any, optional features are implemented (16). The goal of the conformance claim is to allow an analysis of how two devices, each with conformance claims, will interoperate.

HARMONIZATION WITH OTHER STANDARDS

All communication across a computer interface to or from Radiology obeys either explicit or implicit semantic rules and involves an intentional choice of data syntax. Mutual agreement on an information model is the first step toward harmonization of two different information-exchange standards. Achieving this harmonization on a large scale (i.e. international standardization) could strongly enhance the availability of clinical records for timely use in patient care.

Federal Regulation of Medical Software: A Tutorial

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BACKGROUND

The development of complex software systems for applications in medical patient care has led to a heightened concern for liability issues in medical computing and has attracted the regulatory attention of the Food and Drug Administration (FDA), the federal agency having statutory responsibility for medical devices.

Defects in such systems can lead to patient injury and subsequent legal action. The FDA considers all software systems which are components of hardware medical devices or are themselves "intended for use" in individual patient care, without regard to their hardware environment, to be medical devices and to fall within the purview of the Food, Drug, and Cosmetic Act. The Act was amended by the Safe Medical Devices Act of 1990 to require that, after 1991, hospitals and other users of patient care software report product defects to manufacturers and to FDA itself.

DESCRIPTION

The tutorial will briefly trace the development of U.S. regulations for medical products from shortly after the birth of the country to the present time, illustrating the consistency of the philosophy behind the law. Adaptations in the law for medical devices and their application to software will be described. Current regulatory requirements for medical software products will be described.

Current policies and practices within the Office of Device Evaluation (ODE), CDRH, FDA, for the review of premarket applications and notifications for medical software products and required elements of such submissions will be described. Agency experience with these reviews will be summarized.

The legal issues involved in developing, selling and using regulated medical software products will be discussed. As these products proliferate, their potential to injure patients also increases. Typical patterns of software defects and the regulatory and liability consequences will be examined.

Although the question of liability for personal injuries caused by defective medical software products has not been addressed by the courts, it is inevitable that this question will arise in a judicial forum. Users of patient care software products can expect to be targets of patient litigation if injury results or is perceived. The resolution of some of these questions will be attempted by exploring the relevant characteristics of medical computer programs and examining their relationship to the tort law doctrines of negligence and strict product liability. It is concluded that they will be treated as products by the courts, subjecting their manufacturers to strict liability in tort for any defects that cause injury.

As a result, hospitals are likely to face a new source of liability for patient injuries if, under the particular circumstances, they are deemed to be manufacturers or distributors of software products that cause injury. Methods of reducing potential injury and probable consequences of such litigation will be covered.

SESSION 1

**Picture Archiving
and Communication Systems**

Chair: Sridhar B. Seshadri

Overview of the LUX-IMACS Project

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Abstract :

PACS (Picture Archiving and Communication System) is a medical and technological challenge for radiology and related departments of an hospital. In this paper the Luxemburgish national research and development project for integration of PACS in an hospital center, namely the LUX-IMACS project, is presented.

This PACS developed by a multidisciplinary team (physicians, engineers and researchers) for the Centre Hospitalier of Luxemburg is based on medical requirements expressed by the radiologists.

Our approach and working plan to develop this customised IMACS in an open architecture based on existing standards (Unix, C, X-Window, ACRNEMA) is explained.

Technological solutions are shown for each PACS component : integration of radiological imaging system, medical viewstations and workstations, network architecture and images server.

Some interesting original aspects related to this project are presented : use of software engineering methods to analyse the information system and object oriented developments; the concept of voice and synchronized cursor integration for reporting purposes; adaptative image compression to solve problems concerning the management of the huge amount of data; integration with HIS/RIS for optimization purposes (prefetching); introduction of IC-Card as complementary information system and as security feature.

1.INTRODUCTION :

In 1987, the need for an Image Management Archiving and Communication System (IMACS) at the Hospital Center of Luxembourg (CHL) has been expressed by the physicians of the radiology department.

The Hospital Center of Luxembourg is the largest hospital in the country with a capacity of 500 beds, and plays the role of reference center for other hospitals in Luxembourg. Every year the radiology department performs about 125 000 radiological procedures for about 48 000 patients. As more and more modalities are digital (5 already existing digital modalities (1 CT, 1 DR, 1 US, 2 DSA) and within

the next two years digital radiology units will replace the existing conventional devices, and finally an IRM and a second CT will be bought) and because the department of radiology is being split over two different geographic buildings the PACS concept becomes very attractive and an image network will be necessary. Moreover medical requirements expressed by radiologists are based on following aspects [1]:

- the retrieval of previous exams is easier;
- the management of the department is improved (decreasing personal workload, decreasing film costs);
- Diagnostic capacities are improved with possibility of images postprocessing and potential multimodality consultation;
- the production of teaching files for different modalities is possible;
- teleradiology becomes possible.

Because no commercially available ready-made system was able to satisfy clinical expectations and was open enough to connect modalities from different manufacturers, a collaboration with the Public Research Center Henri Tudor (CRP-HT that has R&D activities in the field of image processing, networking, software engineering, microelectronics...) was decided to develop a tailor made PACS based on existing standards. The national research and development project for integration of PACS in the CHL, namely the LUX-IMACS project, was born.

The goal of this project is based on three main points :

- image network for the radiology department;
- extension to the other departments;
- communication with other medical institutions.

To develop this project, the three partners (CHL, CRP-HT and the biomedical department of the Compiègne's University of Technology) formed a multidisciplinary team : physicians (radiologists), radiology technicians, researchers and engineers.

The approach, working plan and technological solutions for each PACS component will be presented in this paper and original aspects will be pointed out.

2.APPROACH AND WORKING PLAN :

The LUX-IMACS project is based on the medical requirements to improve the radiology department by applying new technological tools. In order to end up with this project, a top-down approach (to define optimal implementation for the all hospital level at medical, technical, financial and organizational points of view) and a bottom-up approach (development of prototypes) are used at the same time.

Two phases have been clearly distinguished for the realization of the LUX-IMACS project :

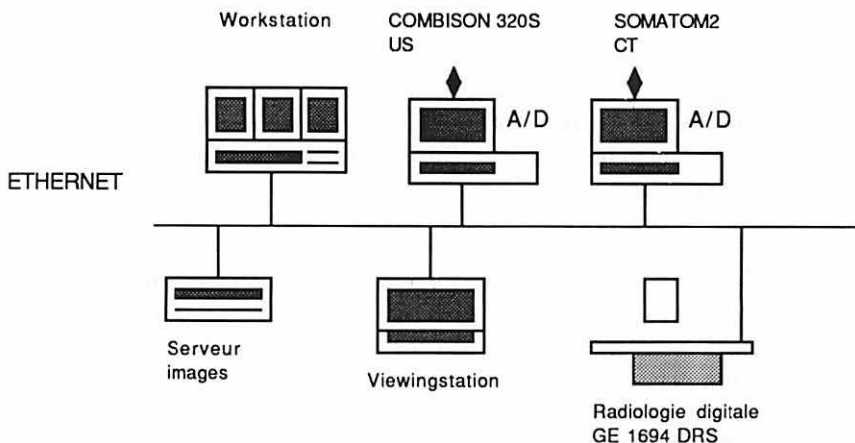
-the phase I (16 months from 1989 to beginning of 1991) which was composed of several tasks concerning preliminary studies (bibliography studies, conceptual analysis, feasibility studies and first prototypes);

-the phase II (1991-1995) for the realization at the CHL which is decomposed in two steps :

- 1991-1993 : first module (cf figure 1) which consists of at least one

element of each component (radiological modalities, workstation, viewstation and images server); at this first stage only the ethernet network is used;

figure1 : first module of LUX-IMACS



-1993-1995 : the whole radiology department will be involved (cf figure 4 of final configuration in network architecture paragraph) and prototypes in other medical departments of the CHL, and other hospitals of the country.

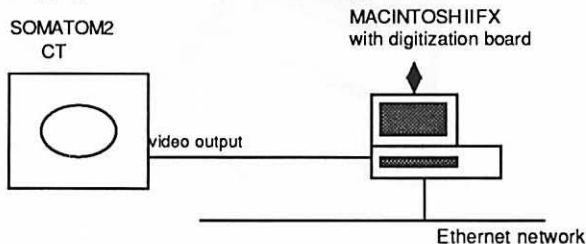
A strategic point concerns the adoption of standards at every level of our work to end up with an open and vendor-independent system. The choice of FFDI, Ethernet for networking, TCP/IP for transfer protocol, Unix for operating system, ACR-NEMA for image format... has been made according to this requirement and allow the transportability of the different applications developed.

3. TECHNOLOGICAL SOLUTIONS FOR EACH COMPONENT :

3.1. Integration of radiological imaging system

3.1.1. Integration of video modalities

In the first module of LUX-IMACS, two modalities, which don't have digital output of images, had to be integrated : an old computed tomograph (Siemens SOMATOM) and an echograph. Therefore we developed interfaces between these



modalities and the network. This interface (cf figure 2) is based on a two screens MacIntosh II fx with an acquisition board to digitize the video output signal. The home made application is written in an object oriented language (C++) and the transfer protocol used between the MacII and an archive server is TCP/IP.

3.1.2.Integration of Digital Radiography

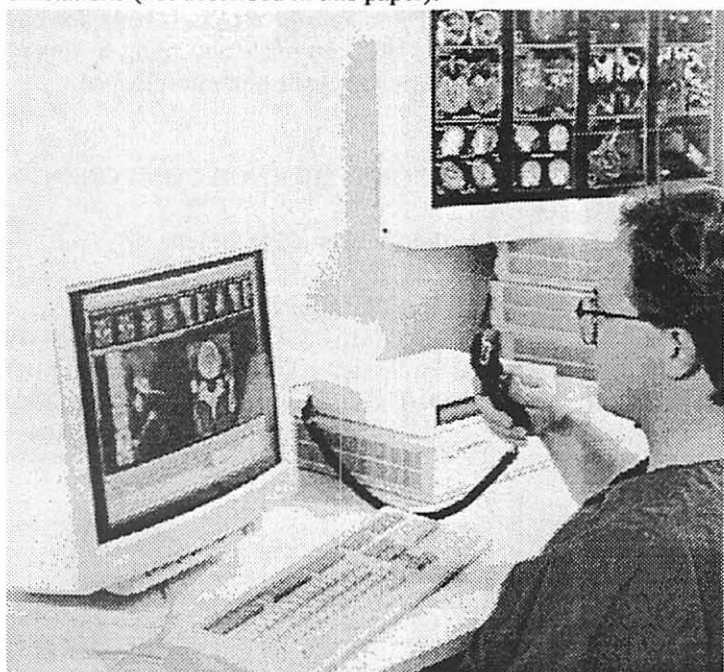
We integrated a digital radiography modality from General Electric (DRS Prestilix 1694) to the ethernet network via TCP/IP. It is the result of hard negotiations between us and the manufacturer who finally gave us their image format and the network connection.

3.1.3.Other modalities

In the final configuration of LUX-IMACS, all radiological modalities will be connected to the network. The same principle described before will be used. We already negotiated with the new CT and the IRM vendors the furnishment of an appropriate interface between their modalities and the ethernet network via TCP/IP.

3.2.Workstations

The conceptual study in this field has led to the distinction between two types of stations : the workstation for the radiologist who produces the diagnosis and the viewing station for the clinician for consulting purposes of their patient examination. By study of bibliography [2][3][4] and by audits of physicians and radiology technicians of the CHL, we defined functional and technical specifications of these two types of workstations (not described in this paper).



We made tests on many Unix workstations (IBM RS6000, HP9000/700, BULL prostation 50, DATA GENERAL Aviion, SUN sparc, DEC 5000/200) with our own benchmarks in order to choose the most appropriate hardware in each case. Here is the choosen device :

-for the viewing station : one screen (1280x1024) station HP9000/720 and DEC5000/133;

-for the workstation for the radiologists : SUN server 470 with VX and MVX boards (image processing accelerating board) and with two screens 1280x1024.

We study the ergonomy of the station to finally develop prototypes of workstations (cf above picture). Applications are developed in C (or C++) with XWindow Motif and image processing libraries (Sunvision and Pv-wave).

3.3.Network architecture and Server

The aim of the project is to create a distributed architecture (cf figure 4) permitting a very flexible management and increasing the reliability of the whole system. It was therefore decided to use a high speed backbone (100Mbps) namely FDDI (Fiber distributed data interface) federating different LANs (Local Area Networks) which integrate devices with lower throughput (physicians viewing stations, radiological modalities, secretary PC...) and keep the possibility for direct connection of devices with high throughput (radiology workstation, image server, laser

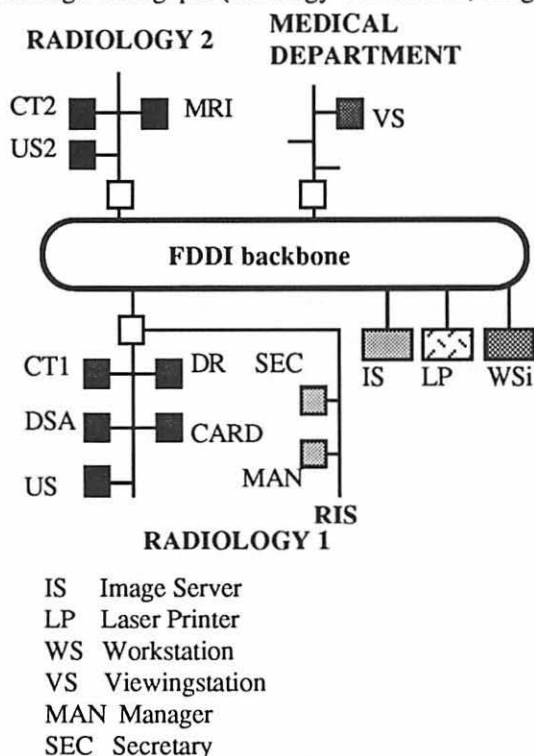


Figure 4 : Final configuration of LUX-IMACS

printer) to the FDDI.

The database architecture will be based on a central image server connected with a juke box, but for optimizing purposes (prefetching) exams will be stored on the local image server (the viewing station itself) for a transitional period of about one week exams. The data base management system will be Oracle. This part of the LUX-IMACS module is not yet implemented, only the conception phase is in process.

Moreover, we just start a study for conception of PACS architecture based on simulation process.

3.4.Laser Printer

A laser printer (Agfa Compact L) will be connected to the network, firstly ethernet and then FDDI, to keep a film output. An interface to ethernet is furnished by Agfa and an application will be made in collaboration with this company in order to call the printer directly from the workstation.

4.ORIGINAL ASPECTS OF THE LUX-IMACS PROJECT

4.1.Use of software engineering method

In order to enhance developments of each component of PACS by different persons, a software engineering method was used to make a modelisation of the PACS. We used an object oriented approach, which modelizes objects from the reality, and we kept attention to remain compatible with the ACR-NEMA standard[7]. It ended up with an internal data representation which is used by developers to better communicate and write reusable programs and will be very useful for the conception of the database.

4.2.Concept of voice integration : Meditalk®

As part of this LUX-IMACS project a development was initiated to use multimedia facilities to enhance communication between radiologists and physicians and secretaries. A multimedia workstation was developed to link radiological images with the vocal report and an active cursor demonstration [5].

This application was made on a Unix workstation with C language and Xwindow Motif windowing system and with a locally developed voice-generation module called Meditalk®. Meditalk® is a digital voice recorder, based on a Motorola DSP56000 processor, which could be connected to every type of computers (Unix workstation, MacIntosh, PC...) via a RS232 line. Remote hand control (microphone and command keys) and remote foot control are available on this module.

Assumed advantages from the link of radiological images to report (text, voice and cursor) are enhanced perception of radiological informations by the referring physician, decrease in communication delays to the physician and to the typist.

4.3.Optimization concepts

For an economically viable IMACS, optimizing concepts are necessary. In the LUX-IMACS project this is achieved at two different levels : image compression and prefetching.

4.3.1.Compression

Image compression is an absolute need in an IMACS for reducing the storage volume and transfer time. With exact coding algorithms, compression rates of about 1: 2 only can be reached whereas irreversible coding may allow higher compression rates, but introducing some distortion.

It is therefore essential to define the maximal compression rate according to the various classes of images encountered (CT, IRM, DR...) [6].

A hierarchical approach to compression has been defined in the project, which can be described as follows :

-after acquisition : exact coding;

-during diagnosis : determination of the representative set of images in the examination and :

-exact coding for the representative set of images

-irreversible coding for the rest of the cluster.

For exact coding of the images we used the Lemple-Ziv algorithm and for the irreversible coding we adapted the JPEG ISO-CCITT ADCT (Adaptative Discrete Cosine Transform) compression algorithm with a rate ranging from 1: 20 according to the image class.

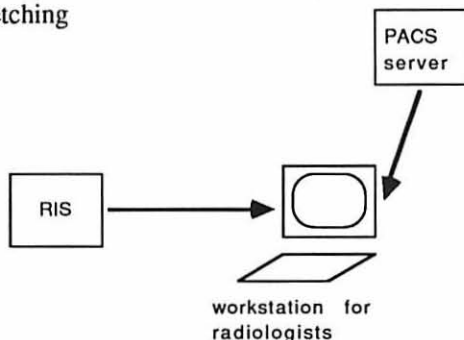
4.3.2.Prefetching concepts

The prefetching concept is used for discharge of the network and is considered in two ways in LUX-IMACS :internal and external prefetching.

*Internal Prefetching (cf figure5) :

It implies a PACS-RIS (Radiology Information System) interaction and permits for planified patients a prefetch of previous exams of the patient on the radiologist workstation. This operation can be fulfilled at night when there is low activity on the IMACS. Thus former exams are localized on the hard disk of the workstation, with no

Figure 5 : Internal Prefetching



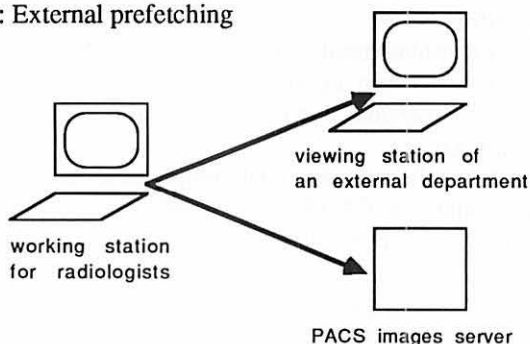
need for additional transaction on the network at time of review.

*External prefetching (cf figure 6) :

It consists in transmitting and saving the exam after diagnosis in a parallel way on the

main image server and on the local image server of the viewingstation of the requesting department. Review of the exam by the physician is achieved through an access to his local database server without network load. A one week exams autonomy was defined for the local server. This implies that network access will just be required

Figure 6 : External prefetching



if the review of an exam older than one week is requested, but that probability is weak.

4.4.IC-card integration

The IC card will be integrated in the LUX-IMACS project in two different ways :

- the Health professional Card will be used as toolbox for high security functions (station access control, data encryption, digital signature ...);

- the Patient Card will work as a complementary information system linked to the Hospital Information System.

5.CONCLUSION

An overview of the LUX-IMACS project at the Hospital Center of Luxembourg has been presented in this paper. Developments are going on and the whole multidisciplinary team is working to end up to a PACS which could be used in clinical routine in the department of radiology. Therefore the compliance to the medical requirements, the use of standards and realization of friendly user oriented interfaces are our main concerns.

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PACS: Price Driven Trade Offs

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The major parameters that define the functionality of a PACS are the speed with which images can be distributed, the quality of the image displays, the security of the data and the operational reliability of the system. Unfortunately, a direct, and sometimes exponential, increase in the cost of the system is invariably associated with improvement in any of these specifications. It is unreasonable to expect most institutions to be able to afford the ultimate system, even if it were available, and, therefore trade-offs must be made to keep costs within an acceptable astronomical level and prevent them from reaching the obscene. With proper design, significant savings can be realized without significant compromise of the system.

A PACS can be divided into functional components which, although intertwined with one another, can be evaluated as individual cost centers: the central computer facility, the display stations, the storage modules and the network that ties them all together.

NETWORK

A network consists basically of the wiring that transmits the data and the devices that distribute the data to the appropriate nodes on the network.

Network media

The various types of cabling differ primarily in the speed with which they can transmit digital data and their cost (Table I). The use of the different types of wire is indicated in Fig. 1.

Media	Cost per 10 feet
4 Pair unshielded twisted pair	\$.72
4 Channel fiber, 50/125 *	16.48
1 Channel 62, 5/125 fiber **	5.10
Thick coax cable (bulk) ***	7.20
Thin coax cable (bulk) ***	1.20

Table 1. Average List Price for Wiring

* Fiber backbone for 4 devices

** Device connection cable

*** Ethernet

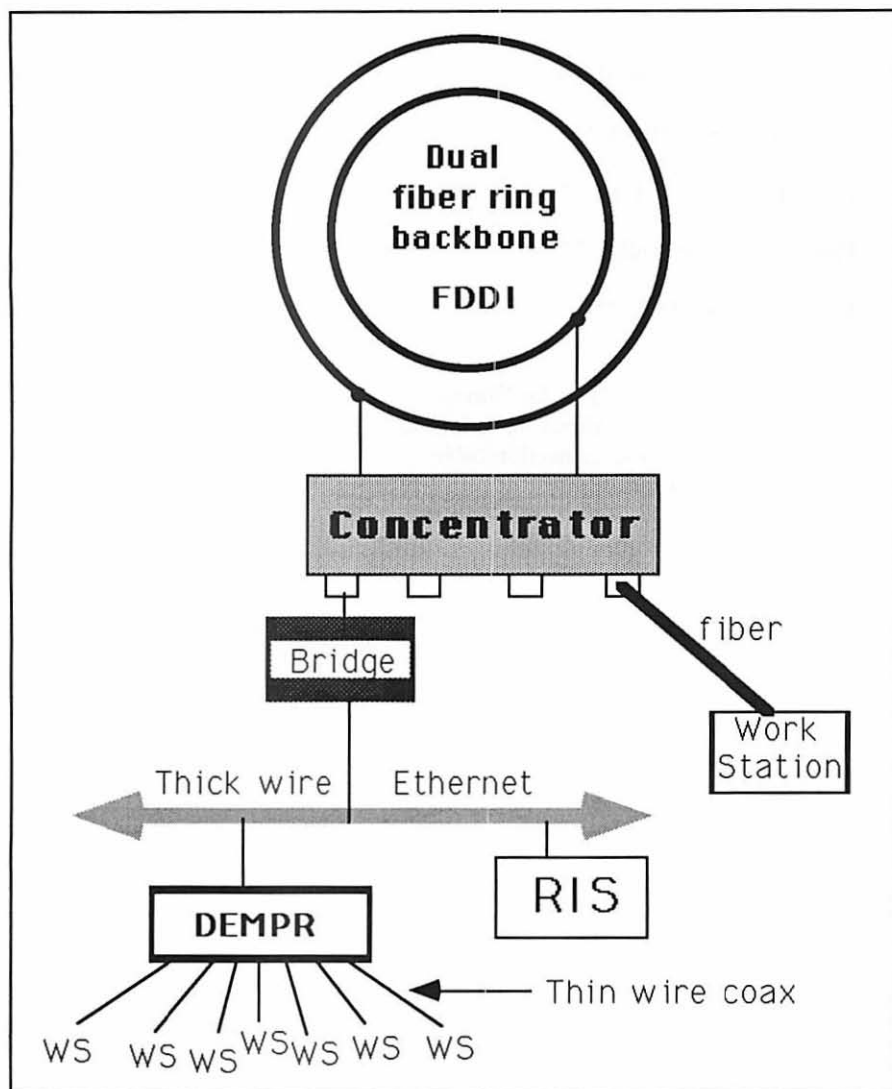


Fig. 1 Network wiring

Thick wire Ethernet is typically used as a backbone where extreme speed is not required. Network distribution units, such as a DEMPR, branch out from it in a tree-like configuration. Both thin wire cable and twisted pair (ordinary telephone wire) are used to connect the devices to the distribution unit. Thin wire is not used for a backbone because it can only support a limited number of devices. It is shielded to prevent noise interference and, therefore, is a better choice for wiring work stations.

Distribution devices

Except in certain specific network designs, it is too expensive and not efficient to run separate wires to each node on the network. The preferred method is to utilize a high speed, high capacity backbone connecting all nodes. In order to keep the size and cost of the backbone within reasonable limits, distribution devices are used so that a single tap from the backbone can be sent to multiple peripheral stations

The hypothetical network shown (Fig. 1) uses dual 4 Channel fiber rings (the duplication is for redundancy) that form the network backbone. This can carry only 4 channels of information at any one time. The concentrator is needed to acquire the signals from the backbone and to distribute them. It is attached to both of the fiber rings. Each channel in the concentrator corresponds to one of the fiber channels. Since fiber can be used only for point-to-point communication, each channel could only lead to one peripheral device. It is very costly to use only fiber throughout the network. However, a specifically designed bridge can be used to connect the fiber cable to a thick-wire coaxial cable that serves as a second network backbone, utilizing only one port from the concentrator. This, in turn, communicates with multiple workstations through a distribution device known as a DEMPR and with the departmental RIS. Two protocols run on the combined network: Fiberoptic Distributed Data Interface (FDDI) on the fiberoptic segments and Ethernet on the coaxial sections. The list prices for these devices (as supplied by DEC) are listed in Table 2.

DECconcentrator 500, 4 channel FDDI, with management module	\$ 11,000.00
DEMPR, thin wire Ethernet Multi- port with tranceiver	3,000.00
DECbridge 500 (Ethernet-to-FDDI)	25,000.00

Table 2: DEC network distribution devices

Network protocols

1. Ethernet

Ethernet protocol has a theoretical speed of 10 megabits/second. Actual speed rarely exceeds 4-5 megabits/sec because of the need for collision detection algorithms inherent in the algorithm which guarantee the integrity of the transmitted messages.

Ethernet is implemented as a bus topology, a continuous run of cable terminated at either end. Peripherals can tap directly into the Ethernet cable but more commonly, a distribution device such as a DEMPR is used to connect to the backbone and then distribute the signal to the peripherals through a star-like arrangement.

Ethernet is a thrifty topology in its use of cable, but it is not particularly fault tolerant. A break at any point on the cable renders the entire network nonfunctional.

2. Token Ring

A Token Ring network is configured as a closed loop with the peripheral nodes connected in series. Token ring networks transfer data at the rate of 16 mb/sec, although they have the potential for considerably greater speeds. The needed equipment to realize these speeds is not available at present.

3. FDDI

FDDI is based on Token Ring technology. However, it can provide speeds up to 100 megabits/sec to any node connected by fiberoptic cable. A twisted pair implementation of FDDI is also available with potential speeds up to 40 mb/sec.

DISPLAY STATIONS

Display stations will differ by the resolution of the CRTs, the size of the monitors, the number of monitors, color or black and white, the amount of onboard RAM, the amount of local storage and the image manipulation capabilities that are available.

Although some vendors supply the same display station regardless of its intended use, there is a clear distinction between the specifications for one to be used for display on a clinical floor and one meant for primary radiological interpretation. The main differences will be in the required resolution of the display and the imaging capabilities. A resolution of 2K x 2K x 10-12 bits deep is generally considered as a minimum for film interpretation. On the other hand, a 1K x 1K x 8 bits is adequate for a clinical display station, especially if the radiology report appears on the screen together with the image.

Similarly, image rotation, zooming magnification fields, ROI calculations, extensive windowing capabilities, etc. are not needed for the clinical station. The simpler, the better. Many clinicians will not utilize the equipment if it involves learning to use a mouse or tracker ball. Unfortunately, stripping off the nonessentials may not save any money. At least one vendor charges a premium of \$250 per display station to disable the unwanted functions.

Except for some nuclear medicine and color Doppler images, a color monitor is not needed. Not only is a black and white monitor less than half the cost of a color monitor, but at any price level, images on the black and white monitor will almost always be perceptibly sharper.

CRTs for viewing stations are expensive and since they are the most numerous items in any PACS, their design has a profound effect on the overall cost of a system. A 19" portrait monitor appears to be a satisfactory format, although smaller monitors can be utilized, at a lesser cost. A major cost factor is how many monitors per work station. In order to have the capability to compare films, two monitors per station are desirable. More than this would be convenient but represents a luxury. This is probably true even for the radiologist's work station.

STORAGE

Image storage on the PACS will be organized similar to film storage in a manual, analog system. At least two areas are required, one for active patients in the institution and one for inactive cases. The active group can be divided into an on-line area similar to the three-day file in some departments and a near-line area for patients with studies done within the last two weeks. The on-line storage will function as a "hot cache" for those images most likely to be requested. Both on-line and near-line storage will utilize rapid access magnetic disks, while off-line storage, which is considerably larger, will utilize optical disks. The cost per megabyte is considerably less with optical disk storage, but the retrieval time is considerably longer from this medium.

Capacity

Decisions must be made regarding what will be stored on magnetic disk. Will it be used simply to hold newly acquired images until they are interpreted, a rather narrow use for this medium, or will it store a greater number of images. The greater the magnetic storage capacity, the greater the number of cases that are almost immediately accessible and the smaller the number of optical disk accesses that will be incurred.

Storage of all active patient data on magnetic disk is desirable, but not an absolute requirement. Actually by utilizing a reasonable combination of image compression and medical compression, large amounts of data may be stored in a reasonable space.

Speed

The tradeoff between magnetic and optical storage is mostly one of time. How long are the physicians willing to wait before they see an image? If they will accept 15 or 20 seconds, essentially all storage can be on optical disk. However, even if this appears acceptable at the start, it will

not be long before the novelty of on-line image acquisition wears off and dissatisfaction with the retrieval delay becomes manifest.

One alternative to the large, central magnetic store is distributed storage where each work station is equipped with its own hard disk. Current images are stored locally so that they can be retrieved very rapidly. Not only can this decrease the required size of the central storage area, but it may also be reflected in a decrease in the required speed of the network, and, therefore, its cost.

RAID (Redundant Array of Inexpensive Disks) is a newer technology that is the fastest magnetic disk configuration on the market today. One vendor uses such an integrated grouping of small hard disk drives for their central storage facility. Workstations are directly connected to this unit, each by its own fiberoptic pipe. Image transmission is very rapid but the configuration is expensive, both in terms of the RAID equipment and the cost of all the individual fiberoptic cables that are required.

Archiving

Here, finally, is an area where better is cheaper. The archival life of data stored on magnetic tape is about 5 years while that on optical disk is quoted as 20 years, and this seems to be an overly conservative estimate. However because of the tremendous size of the image files, optical storage still represents a considerable expense.

Juke boxes with 50 - 100 disks that store over a terabyte of data are commercially available. Each platter costs \$750. It is estimated that a totally digital department would generate about 2300 gigabytes of data for each 100,000 examinations. This is roughly the equivalent of an 800 - 900 bed hospital or a smaller institution with an active outpatient department. Therefore, the disk farm will be filled in less than a year. It is possible to daisy chain these farms, but at a cost of over \$300,000 each, this may not be feasible. The alternative is to dismount filled disks according to age and store them on the shelf. At some point, every system will have to do this. The retrieval time for images off the shelf will be significantly longer than for those images that are still on line. On the other hand, the longer the period of inactivity for any given patient, the less likely that his images will ever be requested. The likelihood of an image being needed, and the retrieval time must be balanced against the cost of keeping it on-line.

REDUNDANCY

A significant price that is paid for the tremendous increases in departmental and institutional efficiency offered by a PACS over a manual system of film handling is the increased vulnerability to disastrous breakdowns. Technologic improvements in computers and networks allow more and more functions to be performed by fewer and fewer devices.

Under the old system, almost any problem other than a calamitous fire or the like, had little effect on the running of the overall department. With a PACS, a simple break in a cable or a disk crash, for example, might bring the entire system to its knees. The possibility of such a stoppage can be avoided, to a large extent, by proper system design.

The surest way to achieve almost total protection is to build two duplicate PACS and mirror all data. Essentially, this would double the cost for the installation and is not feasible. The other extreme would be to retain a hard copy system as a backup. This, too, is financially as well as logistically unacceptable. What can be done is to evaluate the risk of failure of every component of the system and design in safeguards for the more vulnerable and the more critical pieces, when possible, or provide available duplicates. System designs with a single potential point of failure are dangerous.

Network redundancy

The most common source of network disruption is the result of one node going berserk. This cannot really be prevented, but with a properly designed network and good network management tools, the offender can be rapidly identified and silenced.

Less commonly, the problem is due to a fault or a cut in a cable. When dealing with wire, the point of failure can usually be promptly identified and replaced, assuming that the wires are not run in inaccessible locations. Fiber cable is more difficult to patch and it is a good idea to run extra cables to protect against this sort of downtime. Another safeguard that is not inordinately expensive is to place the cables in metal runs so they are not available for accidental cutting.

Central computers

Most modern computers are remarkably reliable. Some are equipped with multiple CPUs that function independently of one another and can take over all functions if one should go down. Without this safeguard, redundancy for the main computer can be provided with a smaller backup CPU that is kept as a "hot spare". The second system can also be used to advantage for testing system upgrades and so on to reduce the risk of downtime associated with software changes.

On-line Storage

Downtime as the result of a disk drive problem is considerably more likely than from a failure of the management system. Complete redundancy of on-line storage can be accomplished by mirroring, where all data is written simultaneously to two disks, but this almost doubles the cost for

on-line storage. A less costly alternative is to have a few spare disk drives. Using a combination of incremental backups and journal files it is possible to reconstitute a working disk within a half hour if the original disk should crash. In the case of scheduled downtime, this could be done during off hours with almost no impact on the system.

Off-line Storage

There is little that can be done to insulate off-line storage against loss other than having a second copy of the data. This should be stored in a distant facility. It is not necessary to duplicate the expensive optical juke boxes for this setup. Calls for the backup data will be quite rare, and storage of optical disks on shelves will be more than sufficient. Nevertheless, the platters are expensive and the size of the required outlay may not be justifiable. Actually, power outages, etc. may disable the optical disk farm in the department but it will not corrupt the data already on disk. It is unlikely that anything short of a massive disaster would destroy the images.

The Integrated Diagnostic System at Medical College of Wisconsin

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At the Medical College of Wisconsin, we have implemented a prototype image management and communication (IMAC) system in collaboration with General Electric Medical Systems and IBM. The Integrated Diagnostic System (IDS) uses a fiber-optic network with an ethernet and ACR-NEMA communications protocol to link three CT scanners, two MRI units, three independent imaging consoles and two workstations in the Department of Radiology. The system includes two workstations in outpatient clinics for referring physicians in gastroenterology and neurology. In all, the system connects two hospitals, an MRI imaging facility and two outpatient clinics.

The imaging systems, independent consoles and workstations are connected to a central 20-GB optical-disk "jukebox" archive; the archive contains 32 5.25 inch magneto-optical disks, each with a capacity of 650 MB. Expansion to a total 100 GB capacity is planned. Images and report text from the Radiology Information System (IBAX-patient care system) are integrated in the archive by the IBM AS/400 archive manager. Intermediate storage and interface to the optical disk jukebox are provided by a storage manager with 1.2 GB hard disk capacity.

The radiologist workstations have two 19-inch screens (1280 x 1024 image matrix, 12-bit dynamic range) with 700 MB hard disk storage. Images are written in a mosaic display either 4/1 (512^2 matrix) or 16/1 (256^2 matrix). Display write time from disk is 5 seconds for four 512 images of 26 seconds for 32 256^2 images. Images can be displayed in an anatomic or numerical order with interleaving or separation of first and second echo images from an MRI pulse sequence. There is an interactive window level display control for single or multiple images to either present or user selectable contrast ranges. There is a select function allowing

deletion of all but reference images from the local hard disk storage and the designation of "summary images" in the central archive. A list images function is available for all studies. Report text can be displayed on one screen and images on the adjacent screen.

The referring physician workstation has a single screen (1360 x 1024 matrix, 8 byte dynamic range) and uses the IBM)S/2 platform with a window based user interface and 120 MB hard disk storage. Images and text can be acquired from the archive using the presentation manager software. Search of the archive manager database by patient name, medical record number or type of procedure is possible. An "electronic folder" concept is used to allow selection of particular studies and selected images. Selected images may be either preselected "summary images" already designated by a radiologist at the radiology workstation or may be independently selected by the referring physician at his workstation. Images and text of reports are displayed in a window format. Single or multiple image displays are possible.

Radiologists selecting summary images at workstations can build a "electronic teaching file." Designated images can be subsequently recalled from the central archive for viewing at the two-screen workstation. This can be used for tutorials and case comparisons. In addition, selected summary images can be sent to an independent imaging console with an attached slave monitor and 35 mm camera for slide production. Film collages can also be produced via connection to a laser multiformat camera.

System Performance

Transmission Speed Per Image

No data compression is used for image transmission and archiving.

Transmission time from imaging system to archive for each CT image is 11 seconds and for each MR image 5 seconds.

Transmission time from archive (magnetic disk) to radiologist workstation is 16.5 second and 8 second for each CT and MR image respectively. Transmission time from archive (optical disk) to radiologist workstation is 22.8 second and 18 second for each CT and MR image respectively.

Transmission time from archive (optical disk) to referring physician workstation is 24 second and 14 second for each CT and MR image respectively.

System load is 300 kilobytes per second with a sustained load capacity of 220-230 kilobytes per second. Image data transfer rate is 30-50 kilobytes per second.

Image data is transferred from acquisition to archive to radiologist workstation where images can be used for study review and diagnosis and selection of "reference" and "summary" images. Referring physicians access the archive by query of the archive manager and may select the whole or a selected part of the "electronic folder." At current transmission rates, this function is best performed in a prefetch mode by a physician assistant.

Image/Report Text Integration

The archive manager requires a medical record number, requisition number, study number and modality in order to match images and text. Medical record number and modality is input automatically by the RIS; requisition number and study number is manually input by technologist. Errors require correction by manual matching in order to maintain database integrity.

Radiology Reports

For CT and MRI studies ordered by gastroenterologists and neurologists, a dictated "priority report" is sent to transcription so that image and text data can be available to referring clinicians at their earliest convenience.

Electronic Teaching File

The electronic teaching file will give radiologist the opportunity and responsibility for generating case material for teaching and research. This should circumvent the cost and logistics of separate film files, while allowing for film and slide reproduction as necessary.

Summary

The Integrated Diagnostic System is a developmental program aimed to enhance the productivity of both radiologist and referring clinicians in patient care, teaching and research. Future developments will place emphasis on fast user friendly interreaction using a distributed workstation environment and a central archive.

Towards the Filmless Hospital – A Progress Report on the Introduction of a Digital Image Archiving System at John Hunter Hospital, Newcastle, Australia

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1. INTRODUCTION

The John Hunter Hospital has taken the first step in the development of an automated image management system through the acquisition of the Toshiba TDIS optical disc archive.⁽¹⁾

The system underwent acceptance tests in early 1992, interfaced to a TCT900S unit and a DFP 60 Angio Unit. As well, pc-based links have been established to ultrasound and nuclear medicine units and a video 8 bit connection to a Siemens Angio unit. The system is connected to two 3M Laser Imagers and can also digitise conventional X-ray films for later reproduction. Digital images can be viewed on either of two 2-Screen workstations with high resolution monitors (1024 x 1536 display matrix) or can be transmitted to 1024 x 1024 monitors in the wards. The system has a retrieval speed of approximately six seconds per image from magnetic disc or 30 seconds from optical disc. During the installation of the system co-operation was maintained with Nagoya University Hospital, Japan, which operates a similar Toshiba TDIS system.

2. UTILISATION STRATEGY

Consideration is being given to the optimum role of the optical disc system in the operations of the hospital. Since opening in 1991 the John Hunter Hospital has experienced a rapid growth, due to the transfer of work from other hospitals in the region. The projected workload at 30 June 1992 is estimated to be 65000 procedures per year consisting of 1000 general X-ray examinations per week and approximately 300 digital examinations, such as CT and angiography.

Given the high volume of conventionally produced films, such as chest x-rays, amounting to some 150,000 per year (50,000 procedures with an average of three films per procedure), there are a number of options for integrating the usage and retrieval of the conventional films and the digital images stored on optical disc. In terms of the use of resources, it was noted during the acceptance trials of the optical disc system that there are scheduling and workforce aspects to be considered. For

example it was established that the optimum method of storing CT images was to use local magnetic disc during the day and then to transmit the images (15 studies x 20 images) in a batch mode to the TDIS system at the end of the day. This procedure takes approximately 40 minutes using an average transfer time of six seconds per image and requires supervision to ensure that the procedure has been completed correctly. In workforce terms, the process of digitising 150,000 films per year would require two full-time technicians and an extensive quality control program to ensure that all images are recorded correctly on optical disc. As an alternative, a study is being prepared on the use of an image plate system to produce digital images which would eliminate the requirement to digitise conventional films. These cost and workforce factors are amongst a number which need to be considered, as well as the preferences of radiologists and physicians and the effects of the operation of the radiology system on the diagnosis and management of patients.

3. COST-BENEFIT CONSIDERATIONS

As part of the cost benefit discussions, a number of options for the management of the radiology function have been examined.⁽²⁾ These options range from:

- converting the hospital to filmless mode with multiple viewing stations throughout the wards;
- operating in mixed mode with conventional films held in a film library and digital images stored on optical disc, available for review on screen or printed out on film, to
- operating in a fully film mode with the optical disc system used for special clinical applications such as the digitisation of portable chest films and the transmission of the images to screens in the Intensive Care Unit.

Economic modelling, including both tangible and intangible costs and benefits, has been performed in a number of countries for a variety of radiology systems. A detailed study by Warburton and others⁽³⁾ reported that the operation of a digital image system was likely to lead to additional costs of 12–17 per cent annually. In the present economic climate, funding agencies are more likely to provide support for on-going expenditure on salaries and consumables than to allocate large capital sums for digital system development. However, it needs to be recognised that the adoption of an apparently low cost option such as the full film system, would involve capital expenditure in the construction and operation of a conventional film library and archival storage system.

4. THE FUTURE

There remain a number of paths towards the filmless hospital. In order to provide information to assist hospital administrators and physicians to develop a suitable approach, a number of small scale projects are being undertaken. The TDIS system is being used to digitise portable chest X-rays which can then be transmitted to a 1024 x

1024 screen in the Intensive Care Unit for use by physicians in the management of patients. This project can assist in the development of user-friendly software to enable an assessment to be made of physicians acceptance of working with images on screen, thus replicating previous work done by Arenson and others.⁽⁴⁾

As well, a proposal has been developed to conduct a large scale Receiver Operator Characteristic (ROC) study on the interpretation of chest images using the TDIS high resolution work station. The study is designed to replicate the work of Slasky and others⁽⁵⁾ at the University of Pittsburg in an Australian environment. It is hoped that the conduct of these studies will allow radiologists and physicians to gain an understanding of the capabilities of a digital radiology system and lead to a physician-driven demand for a digital radiology system rather than the imposition of an unfamiliar system on physicians used to working with conventional film. Meanwhile, the experiences of other filmless radiology projects such as Hammersmith Hospital, London and Madigan Hospital, Tacoma, Washington will be watched with interest in order to develop guidelines for the future management of radiology services in Australia.

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SESSION 2

**Veterans' Administration
Applications**

Chair: Eliot Siegel

Medical Images as an Integral Part of the Patient's Automated Record

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I. The DHCP Hospital Information System

The Department of Veterans Affairs (VA) operates the largest health care system in the Federal sector, consisting of 169 medical centers, 228 outpatient clinics, and 117 nursing homes. The VA uses a hospital information system (HIS) developed and maintained by its own staff called the Decentralized Hospital Computer Program (DHCP). DHCP is written in ANSI standard MUMPS and runs on a variety of hardware platforms. DHCP is in the public domain and is used in 166 VA Medical Centers, as well as in derivative form by the Department of Defense, the Indian Health Service, other government agencies, and private hospitals worldwide. This internal system development approach provides compatibility among systems in all of the VA facilities that enables the development of distributed applications involving the exchange of data between facilities. It also allows the VA to enhance its HIS to meet constantly changing user requirements and to provide leadership in innovative hospital information system functionality.

The VA's DHCP system is different from multi-vendor systems in that it is an integrated system based on a central set of software development tools. These tools, produced by the VA, include the VA File Manager, a powerful database management system that includes extensive software development facilities, the VA Kernel which provides vendor independence, and various tools for menu management, output device control, security, task scheduling, and electronic mail. All of DHCP's many software modules, such as the laboratory, pharmacy, radiology, surgery, medicine, health summary, local and regional registry modules, are based on the VA toolkit and adhere to its rules. A modular architecture is used to allow easy integration of new technology as it becomes available.

The VA's DHCP systems typically run on Digital Equipment Corporation (DEC) VAX minicomputers in a VAX cluster architecture [1] or on a network of Intel 80486-based microcomputers. Data processing is distributed among the machines in a client-server fashion so that the application software and the databases are located on different network nodes. The Distributed Data

Processing protocol (DDP) is used to communicate between nodes.

II. DHCP Integrated Imaging System

The VA has recently implemented a unique distributed system that manages medical images as an integral part of its HIS (see Figure 1). Imaging workstations located throughout the hospital capture and display a wide variety of medical images, including cardiology, bronchoscopy, gi endoscopy, hematology, surgical pathology, surgery, dermatology, and radiology images. The goal of the VA's DHCP Imaging System is to provide image and text data in an integrated manner that facilitates the clinician's task of correlating that data and making patient care decisions in a timely and accurate way. This system is oriented toward providing the treating physician with a complete view of patient data, and at the same time allows consulting physicians to have access to that image and text data. Its potential as a tool to aid communication and consultation among physicians is enormous -- whether in the same department, in different medical services, or at different sites.

The DHCP Imaging System uses a local area network to connect imaging workstations to multiple magnetic and optical disk image file servers and to the DHCP hospital information system running MUMPS. Thus, the workstations are the clients of two different types of servers and support two separate networking protocols. The entire suite of DHCP applications runs on the imaging workstations with all patient text data being accessed from the HIS patient data server. The HIS server supplies information about each image, including control information about the imaging software, the list of components making up the image object, and its attributes. The imaging workstation HIS software uses this information to access image files and to control image display. All images and text data are available from any medical center workstation to users with access privileges.

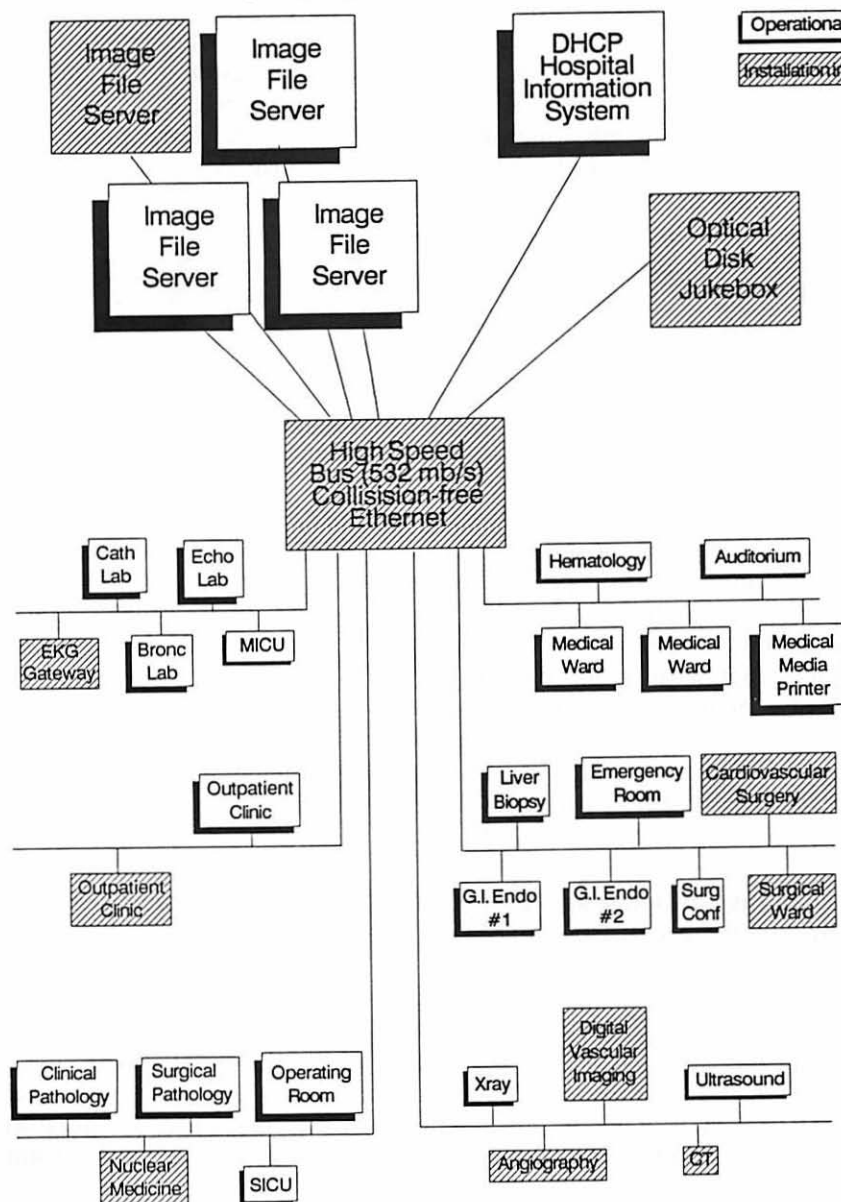
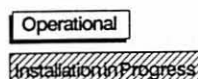
The local area network uses ethernet (IEEE 802.3) in a star concentrator/hub topology. All of the workstations on each floor are connected to a concentrator located in the floor's wiring closet. The concentrators are connected via fiber optic cable run vertically in the wiring closets to the high speed router hub located in the computer room. Each concentrator and each server is connected to a separate ethernet port on the hub, isolating collisions to each segment. A bridge passes MUMPS DDP packets between the imaging network segment and the HIS server segment.

The DHCP Imaging System is currently being alpha tested at the Washington DC VA Medical Center. The imaging workstation platform used in the prototype installation is based on an AT-compatible 80386 systems containing an imaging board with a graphics co-processor and four megabytes of onboard memory [2]. The use of two high resolution, color

Figure 1:

Washington DC VAMC DHCP Imaging System Installation Status

KEY:



monitors allows the simultaneous display of images with clinical text. The workstation meets clinicians needs for true color displays of up to 16 million colors per pixel to handle pathology, dermatology, and endoscopy images; for variable spatial and color/grayscale resolution; and for digital image capture on the workstations.

Workstations are located in a number of departments and patient care areas. Image input workstation locations include the cardiology department, gastroenterology endoscopy lab, bronchoscopy examination room, surgical pathology reading room, hematology research laboratory, liver biopsy reading room, dermatology clinic, emergency room, rheumatology research lab, operating room, radiology department and nuclear medicine department. There are image display workstations in patient treatment areas and conference areas including the clinical wards, emergency room, outpatient clinics, and intensive care units. An image printer is located in the medical media department. Images are generally collected by consulting services to meet their own needs as well as the needs of the referring physicians.

The project is looking at the implications of this capability as an aid to communication among physicians in a hospital setting. System accesses have been recorded to help measure the usage of images by physicians in different services. Images are viewed both by the collecting service when producing procedure reports and consultations, as well as by referring physicians from other hospital services. Medical departments have developed image collection policies to meet their internal needs and the needs of referring physicians. Staff members from a variety of hospital services display images on various workstations throughout the hospital. The services that acquire images perform 55% of the total image accesses. Treating physicians such as medical service, nursing, and surgery, account for 35%. Inter-service or inter-subspecialty viewing accounts for approximately half of the image viewing. Most image viewing involves multiple physicians, either during conferences, rounds, morning report or consultations where a number of physicians are involved.

III. Exchange of Image and Text Data Between DHCP Imaging System and Commercial Radiology PACS System

The VA is extending its development of integrated imaging capability at the Baltimore VA Medical Center. A new 324-bed replacement medical center is being completed with occupancy scheduled for November 1992. Both the DHCP Imaging System and a commercial radiology PACS system will be installed at this site. As at the Washington DC installation, the DHCP Imaging System will record clinically significant

diagnostic images selected by medical specialists in a variety of departments.

A Siemens-Loral Radiology PACS system supports image acquisition devices that transmit digital images to a 40 GB magnetic working storage unit. A VAX 4000 host processor with a Sybase relational database controls all image acquisition, storage, and retrieval. Long-term storage is provided by a 1.02 terabyte Kodak optical storage jukebox. PACS workstations are Apple MacIntoshes with black and white image display capabilities. The PACS is designed to rapidly provide very high resolution black and white images to radiologists. The department plans to operate in a film-less, all digital mode.

There is a need for bidirectional exchange of both images and text between the two systems. The PACS requires current patient identification, demographic data and order entry information to operate properly. This information is always entered or modified on the DHCP system. Radiology reports are very desirable since they can be displayed with the images on PACS workstations. Changes in reports (i.e., amendments) and changes in exam order information are also necessary. Current patient tracking information is very useful for display of patient information by ward. Some locations will have only a PACS workstation, therefore, all DHCP images must be available to the PACS. DHCP color images must be converted into black and white for the PACS.

The PACS generates information that is needed by the DHCP system. Exam completion notification must be sent to DHCP in order to update the order status. The PACS must also send to DHCP a list of the images associated with each completed order so that related images and text can be displayed for users in an integrated way. DHCP must be able to retrieve any PACS image for display on its imaging workstations. Some PACS images will be reduced in size when sent to DHCP. The PACS must provide a mechanism to differentiate the clinically significant radiology images from the routine images. By default, these clinically significant images will automatically be retrieved from the PACS and stored on the DHCP magnetic file servers. Additional PACS images can be copied across the interface on request.

The interface uses messages based upon the ACR-NEMA 2.0 Standard extended with shadow groups and published ACR-NEMA 3.0 prototypes (see Table I) [3]. A Novell file server, accessible to both systems via Ethernet, is used to communicate all messages. Patient identification information, orders, ADT, procedure status, changes, patient reports, and images are sent between the two systems across the interface.

The interface follows the "ancillary service-to-hospital information system" model successful for over a decade [4,5]. Each ACR-NEMA message is stored in a separate file on the server. The files are processed in a sequential first-in-first-out order. After each message is processed, the ACR-NEMA response message is stored on the file server in a similar manner.

The interface is designed to be "loosely-coupled" and permits relatively complete separation between the PACS and the DHCP Imaging System. This approach allows each side of the interface to be completely tested in the absence of the other using a known input stream. It also permits each system to be operational (for a short time) without the other, and allows one system to "fall behind" the other and then "catch up". In addition, it provides an audit trail of all transactions. A "tightly-coupled" interface using a remote procedure call to transmit messages directly

Table I: Types of Messages used to exchange data between DHCP and PACS systems

Message Type	Direction of Communication
Order Entry	DHCP-->PACS
Patient Demographic Change, Merge	DHCP-->PACS
Exam Completion	DHCP<--PACS
History Folder Update	DHCP<--PACS
Get PACS Image	DHCP-->PACS
Send Image	DHCP<-->PACS
Radiology Reports	DHCP-->PACS
Amended Reports	DHCP-->PACS
Order or Exam Change	DHCP-->PACS
Patient Transfer	DHCP-->PACS
Patient Admission	DHCP-->PACS
Patient Discharge	DHCP-->PACS

between systems might give quicker performance, but would be harder to implement and lacks these features. The interface is designed to be compatible with other commercial PACS systems.

IV. Discussion and Conclusions

The VA's DHCP Imaging System is unique because of its emphasis on the referring physician user and its integration of multi-specialty images with text data stored in an existing complete hospital information system. Its bidirectional interface capable of exchanging both text and image data with commercial PACS systems will be the first such interface for an HIS or a PACS system.

The VA's DHCP Integrated Imaging System has been received very well by its users, and serves as an incentive for clinicians to use the hospital information system. The Imaging System is meeting real needs for integrated image and text data that cannot be met in other ways. The VA's unique development environment presents the opportunity to explore the implications of image integration for the next generation of hospital information systems.

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Picture Archiving and Communication Systems (PACS): A Medical Device

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Purpose

This paper clarifies the role and significance of PACS in medical practice. It emphasizes the importance of classifying PACS as medical devices rather than as collections of ADP¹ equipment. The distinction has major implications for planning, funding, administration and professional integrity.

Developmental History

A PACS is a direct extensions of a radical shift in the technology of image acquisition and formation introduced commercially in 1972². The shift occurred with the introduction of Hounsfield's Computer Assisted Tomography (now called CT). CT employed completely electronic means to create digital images for display on Cathode Ray Tubes (CRT). CT thereby introduced a clinically useful alternative to photographic film for detecting radiation. This technical milestone was not appreciated during the initial explosive diffusion of the new technology. The clinical potential of CT was.

Also appreciated then was the technical value of image formation techniques used to produce CT images. These methods were quickly applied to other modalities. Ultrasound (US), nuclear medical imaging, and various forms of fluoroscopy like digital subtraction angiography (DSA) followed in months. Magnetic Resonance Imaging

¹ Automated Data Processing.

² Hounsfield GN: A method of and apparatus for examination of a body by radiation such as x or gamma radiation. Patent specification 1283915. London: August 1972.

(MRI) and many less universal modalities also use a similar digital electronic technology. Finally, a new but clearly established technology called "Computed Radiography" (CR) promises to provide the means for a complete transition from film to digital electronics in the intermediate future. The possibilities of filmless imaging, based on solid experience, have now begun to draw the appreciation that they are due.

In simplest form, each of these modalities is a small PACS dedicated to a single image acquisition device. Each contains, in addition to the acquisition device itself, the common elements of a PACS. There is a means to display, manipulate, and store images, an image database management system, and hard copy printer. Images are communicated among the components. Early in digital imaging history, it was common to share devices. For example, CTs often shared a "physician's console" which was used by clinicians to view completed studies while technologist operators continued to use the main console to conduct new studies. With console sharing, communication reached another level of sophistication. However, it would be difficult to think that the simple act of sharing could change the fundamental character or classification of the physician's console. The console remained a medical device. Similar sharing is now possible and common with storage devices, hard copy printers, storage database managers, and other devices. Just as it was not suggested that sharing was cause to consider the console ADP equipment, sharing through the use of radiology networks is not a reason to re-cast attitudes toward basic radiologic instruments.

During the last decade, much PACS research and development has been accomplished by a host of Universities and by several vendors. The Army has fostered specification development and several implementations. Both the Japanese and Europeans have major installations. PACS of varying complexity are established in private sector centers. Sharing at a section or department level has evolved to a point where the PACS concept has matured as a clinically valuable, commercially developed entity.

However, the fact that PACS can be considered and sold as a discrete entity should not allow us to forget for a moment that this new technology is fundamental to medical imaging and therefore carries with it all of the elementary needs for radiologists to display, manipulate, store, and share images that are the classic hallmarks of radiologic practice. Regardless of whether a radiologist uses films or electronics, the basic medical process remains the same.

Transfer of digital electronic images to film for viewing, storage, and sharing (communication) has been the common practice. However, film is far from trouble free, and it is expensive. Consequently there is growing interest in exploiting the advantages of this alternative technology, particularly when this electronic methodology for image management has been evolving under routine use since introduction of the first CT. It is fact that, although film has persisted as the final storage medium, images are initially viewed on a Cathode Ray Tube (CRT); they are manipulated to best display diagnostic features; and they have been routinely stored on discs and magnetic tapes. Often consultations are conducted around the CRT as well, and when films of these electronic images are misplaced, the electronic images may be retrieved for CRT review or reprinting.

If one realizes how mature many PACS concepts and practices are, and if one realizes how analogous these are to the practices of film based radiology, then it can be understood that PACS, or partial PACS, within radiology departments, or as connections to satellite departments are evolving fundamental tools of radiologic practice and are therefore medical devices. In practice, PACS are expansions of and inseparable from acquisition devices because they are part of the chain which leads to the professional diagnostic act. The physician's evaluation of the transported and manipulated image requires that he (she) has full knowledge of how it was derived, managed and modified. He must know the display characteristics and the limitations of the entire formation and presentation process of electronic images just as he knows those elements of the films, screens, physics and chemis-

try of traditional radiology.

This perception that PACS are medical devices has been expressed by the professional community in a number of ways. Commercial development of PACS has targeted individual specialties such as radiology and nuclear medicine. Marketing has presented PACS as devices for the specialties. Manufacturers and professionals working together have started with the acquisition devices in developing sharing standards³. It is significant that the Department of Defense/Army, in confirmation of this concept, has defined PACS as a medical device and so describes it in contract documents⁴.

Systems Distinction between PACS and ADP⁵

The widespread, general acceptance of PACS as a medical device in spite of the similarity of certain ADP and PACS components, is largely intuitive. It recognizes the crucial role that images as described here play in radiologic practice. To consider PACS systems within radiology departments as anything other than radiology devices, of integral importance to the basic equipment of radiologic practice, seems to most practitioners illogical and dangerous to the dispatch of professional responsibilities.

However, there is additional solid supporting logic. One might ask, "Why is a component, such as an optical disc storage unit, or a data base management system, considered a part of a medical device in one instance and ADP equipment in another"? The principle used to differentiate is sound systems theory. Systems are built of nested sets

³ The American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) have combined their efforts since 1984 in developing the ACR/NEMA standards starting with the acquisition device plug through which images are exported to ancillary devices.

⁴ DACA87-90-R-0058, page C-3, section 1.2.1., "The MDIS system is a network of computer based medical devices that..."

⁵ Automated Data Processing.

of components; that is, they have a hierarchical organization. "Every system is embedded in a larger system."⁶ when one is defining systems as they support organizational purpose, one must decide at what system level to protect integrity, thereby defining the meaningful system component and conferring upon it a name. The natural evolution of digital electronic systems has perceived such a system component and conferred upon it the name of "PACS". In medical systems, components may be highly complex--more complex than first intuition might dictate. If our purpose is to enable a professional to perform some medical act(s), all of the necessary support equipment for that act(s) must be available under a single authority and must answer to one management. This is the single, strongest argument for classifying PACS as a medical device. It cannot be farmed out in pieces. For instance, it is not sensible in a traditional setting to provide an x-ray machine through Radiology and a film processor through Medical Media just because one component of the image management chain deals with radiation and the other deals with "pictures". Similarly it is not sensible in a digital electronic setting to provide an x-ray machine through Radiology and image processing equipment through ADP just because the processor contains a computer as one component. This comparison is a simplistic but relevant example of how improper premises can lead to the mis-classification of PACS as ADP equipment.

When one is identifying a cluster of people and devices critical to the achievement of a defined purpose such as the practice of diagnostic radiology, there are value judgments involved that are more difficult and less clear cut than the decisions one makes when classifying simple units by single criteria. Often there may be more than one perspective and more than one line of demarcation between system levels. When optional demarcation lines vary significantly from one to another, the overlap among the options represents common ground which may be addressed in more than one way. One discovers a fairly broad overlap when analyzing the relationship between a

⁶ Churchman CW: *The Systems Approach*. New York, Dell Publishing Co., 1968, p.48.

radiology PACS and an image handling Hospital Information System (HIS). For instance, state of the art PACS often require that images be transmissible between radiology and the Intensive Care Unit (ICU). This could be accomplished either by a dedicated extension of the radiology PACS or by services of an HIS. During these transitional years, the first solution might be implemented with the intent of transferring the extension when a second option is implemented later, e.g., radiology service to the ICU might be later transferred when the HIS⁷ is upgraded to handle images.

Prior to implementation of image handling, it might be useful to automatically receive patient data, such as identifiers, into a PACS system. This is a benefit, but hardly a prerequisite for PACS. Many configurations and many implementation schedules involving both PACS and HIS exist, but the development of neither is or should be dependent on the other. When PACS and HIS co-exist and communicate in the future, they may be expected to interact with synergy to the immense benefit of the medical community and the patient.

Conclusions

1. The radiology PACS is already an absolutely essential component of radiology departments with several digital acquisition devices. Implementation is proving to be incremental and to vary from medical center to medical center. Need for support from PACS is implicit in the latest imaging technology. Radiology PACS is a basic medical device available in many commercial configurations.
2. Communication of images by electronics rather than by physical transport of film is a natural implication of PACS.
3. Communication and other image services outside of the radiology department is a natural HIS service and an appropriate

⁷ The VA calls its HIS "Decentralized Hospital Computer Program (DHCP)".

objective for DHCP and other HISs.

4. In spite of the complementarity of PACS and HIS, they are not related to medical practice in the same way. The difference is based on a complex but fundamental system rationale. PACS and HIS have been generated independently by different medical needs and serve different types of support functions. They can and should proliferate independently in an environment of rich exchange.

5. Eventually the General Service HIS or its successor will meet acquisition based, specialty networks like radiology PACS on common technical ground. It will then be essential that design, funding, and management of these communicating systems be based on balanced, multidisciplinary comprehension of the complex medical functions to be served.

SESSION 3

Image Processing

Chair: Robert A. Greenes

A Fuzzy 3-D Display Method of Multichannel MR Images

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1.INTRODUCTION

A 3-D display allows better perception of the continuity of structures and spatial relationships than a display of individual slices [1]-[10]. However, it is difficult to extract organ shapes from medical images. Soft tissues, like a tumor, have fuzzy shapes while the value of these boundary regions continuously vary. Therefore the techniques suffer from the common problem of having to make a binary classification decision; either a surface passes through the current voxel or it does not. Errors in classification manifest themselves as visual artifacts in the generated image. Thus proper classification of normal or abnormal soft tissues is required to represent the continuity of the sample array.

We use multiple 3-D MR images of the same anatomical section using different pulse sequences to improve the accuracy of tissue extraction. This tissue extraction method consists of a three-step process. The first step is to build linear or nonlinear combinations of multichannel MR images. The second is to operate the fuzzy c-means clustering [10]-[12] on the combined MR images. An efficient 3-D fuzzy c-means clustering is implemented to reduce much computation time and memory.. The third step is to extract soft tissues of interest from the tissue clusters by checking the connectivity of a tissue shape.

The shading of extracted organ shapes uses volume rendering [6]-[8]. The shading model is formed to realize an interactive 3-D display.

T1-weighted images, T2-weighted images, PD-weighted images and MRA images of human brain are combined linearly or nonlinearly. A complicated discrimination of white matter, gray matter, CSF, blood vessels, and their spatial relationships are recognized.

2.COMBINATION OF MULTICHANNEL MR IMAGES

Magnetic resonance imaging discriminates between soft tissues more precisely than other currently available imaging modalities. The gray-level distributions between different soft tissues in MRI are not widely separated. With MRI it is possible to obtain multiple images of the same anatomical section using different pulse sequences. Each image has a different response characteristic to each soft tissue class. Based on these images, we can use multichannel analysis to perform tissue extraction. This property of MRI has the potential for improving the accuracy of tissue extraction.

First, we describe a linear combination of each image to contain a mixture of multichannel MR images. It can be described mathematically as follows.

$$f_p(x,y,z) = \sum c_i * f_i(x,y,z) \quad (1)$$

where $f_p(x,y,z)$ is the value of the pixel element (x,y,z) on the processed image, $f_i(x,y,z)$ is the value of the pixel element (x,y,z) on the i -th channel MR image, and c_i is a weighting factor of the i -th channel MR image.

High performance of the extraction is obtained by choosing a proper value for c_i . A rectangular region including a soft tissue of interest is roughly specified on each channel image. Each pixel value on the specified region is mapped on the Cartesian feature space corresponded to each channel image. A line is set in the feature space. Each coordinate point is projected on the line. Linear combined images are calculated. The weighting factors c_i are decided from the line equation. The line equation are interactively parameterized by the data distribution. T1-weighted image, PD-weighted image and their linear combined image are compared. Basal ganglia is discriminated.

Next, we describe a nonlinear combination of multichannel images. This nonlinear combination is calculated by using a distance measure. The distance measure is mathematically as follows.

$$d_i(x,y,z) = |f_i(x,y,z) - f_s(x,y,z)| \quad (2)$$

$$D(x,y,z) = \sum (\alpha_i |d_i(x,y,z) - d_i(x_s, y_s, z_s)|) \quad (3)$$

$$\sum \alpha_i = 1, \quad \alpha_i \geq 0 \quad (4)$$

where $f_s(x,y,z)$ is the value of the pixel element (x,y,z) on the standard image, $f_i(x,y,z)$ is the value of the pixel element (x,y,z) on the i -th channel MR image, the pixel element (x_s, y_s, z_s) is a sample point of interest on each channel image and α_i is a weighting factor of the i -th channel image.

The result of extraction is shown in Fig.1. Fig.1 shows T2-weighted image, T1-weighted image, PD-weighted image

and a nonlinear combined image. This standard image uses T2-weighted image and a sample point of interest is appointed on a region of CSF. CSF and basal ganglia is discriminated.

3. FUZZY CLUSTERING OF COMBINED IMAGES

A fuzzy c-means clustering (FCM) is used to extract the soft tissue from the combined images. The FCM is as follows [10]-[12]. Let a number of extracted 3-D data sf_i and a number of clusters be denoted N and C , an estimate value u_{ij} of sf_i in the j -th cluster is given by

$$\sum u_{ij} = 1, \quad 0 \leq u_{ij} \leq 1 \quad (5)$$

The cluster u_{ij} is measured by searching for the local minima of the following equation J which is generalized with the sum of the squared error objective function;

$$J = \sum \sum u_{ij}^m (sf_i - g_j)^2 \quad (6)$$

g_j is a cluster center of the j -th cluster and m is a weighing exponent. u_{ij} and g_j may be a local minimum of J only if

$$u_{ij} = 1 / (\sum ((sf_i - g_j) / (sf_i - g_k))^{2/(m-1)}) \quad (7)$$

$$g_j = (\sum u_{ij}^m sf_i) / (\sum u_{ij}^m) \quad (8)$$

The FCM is defined by iteratively looping through (7) and (8) until a convergence condition $|u_{ij}^{(s+1)} - u_{ij}^{(s)}| < \epsilon$ is satisfied.

This 3-D FCM requires much computation time and memory. To avoid the problems, an efficient FCM is developed. The data representation of MR images uses the length of 12 bits. The range of the value is remarkably smaller than the size of the 3-D data. This feature is applied to the FCM. The proposed method consists of making a histogram of the 3-D data and applying the FCM to this histogram. The procedure is as follows [10].

1. Let n_b denote a frequency with which gray level p_b occurs in 3-D data sf_i , all sf_i exist in the gray level range (p_l, p_r). p_l is larger than 0 and p_r is less than 4096. n_b is given by

$$n = n_1 + n_2 + \dots + n_r \quad (9)$$

2. An estimate value v_{bj} of p_b in the j -th cluster is given by

$$v_{bj} = 1 / (\sum ((p_b - a_j) / (p_b - a_k))^{2/(m-1)}) \quad (10)$$

$$a_j = (\sum v_{bj}^m n_b p_b) / (\sum v_{bj}^m) \quad (11)$$

a_j is a cluster center of the j -th cluster.

3. The FCM is computed by iteratively looping through (10) and (11) until the following convergence condition is satisfied.

$$|v_{bj}^{(s+1)} - v_{bj}^{(s)}| < \epsilon \quad (12)$$

4. Using the correspondence relationship of p_b and sf_i , v_{bj} is corresponded to u_{ij} .

The present method is compared with the method of (7) and (8). The memory size is compared in the case of 128×128 images, a word length of 12 bits and $c=n$. The present method decreases four times the method of (7) and (8). In case of the same number of the gray level, the larger the size of the image data, the more efficient the present method is.

The computation time is compared in the case of 128×128 images, a word length of 12 bits, $c=4$, and $m=2$. The computation amount of the present method is about $1/16$ of the method of (7) and (8). These methods are actually implemented on a UNIX workstation, the present method is 20 times faster than the method of (7) and (8).

The FCM converts the image data to a set of cluster arrays. The organ of interest from the set of cluster arrays is extracted. But, the FCM is a clustering of image values and not a clustering of location parameters. Each cluster remains within the several cluster distributions on a 3-D image space. The organ shape of interest is extracted by using the spatial connectivity of organ shapes.

The MR images are proceeded to the tissue extraction process. Fig.2 shows the results of the FCM with $m=2$, $c=4$ and the connectivity check of organ shapes. First, a cluster of the gray matter is extracted by the FCM. Next, the gray matter is extracted by checking the connectivity of organ shapes. In the top left is a slice of the human brain. In the top center is a cluster u_{ij} of the gray matter. In the top right is the gray matter region. The bottom is a relationship between the image values and cluster values v_{bj} of the gray matter. Other extracted clusters are consistent with a cluster of the air and bone, a cluster of white matter and a cluster of CSF. But the performance of the FCM is dependent to the search range and the number of clusters. These adequate parameters are selected interactively by an anatomy knowledge and an inspection of images.

4.3-D DISPLAY OF ORGAN SHAPES

We use volume rendering[6]-[8]. Volume rendering is formed by computing the volume data of the opacity and the shaded value from the volume data of organ shapes, and projecting it's volume on the image plane.

The opacity α uses a volume data of the organ shape. The shaded value is computed by an inner product of a vector of

the light source and a normal vector of each pixel. This projection is calculated in back-to-front order or in front-to-back order. The calculation method in front-to-back order can be executed in high speed. A shading model is as follows.

$$\eta_{i+1} = w * \alpha_{i+1}^q \quad (13)$$

$$\gamma_{i+1} = (1 - \eta_1) \dots (1 - \eta_i) \eta_{i+1} \quad (14)$$

$$S_{i+1} = S_i + \gamma_{i+1} J_{i+1} \quad (15)$$

where η_{i+1} is the $i+1$ -th opacity which consists of a product of a weight coefficient w ($w < 1$) and the $i+1$ -th opacity α_{i+1} to the q -th power, J is the shaded intensity which is computed from the opacity. The opacity and the shaded value of the $i+1$ -th sample are computed by a linear interpolation of the 8 nearest neighborhood data at the $i+1$ -th sample. γ_{i+1} and S_{i+1} are the integrated opacity and the integrated shaded intensity of the ray tracing from the eye view to the $i+1$ -th sample.

The opacity α to the q -th power in (13) can adjust an intensity of the volume data of organ shapes. The weight coefficient w in (13) can also adjust an intensity of the volume data to a smaller intensity. The shading computation is started in front to back order and ended when γ_i is very small and S is saturated. By controlling q and w , desirable 3-D display can be chosen interactively in order to support diagnosis and surgical planning.

3-D display of the tissue volume data is calculated. The brain MR images are $256 \times 256 \times 128$ images in which a pixel size is 1 mm and the size between images is 1.5 mm. After applied the FCM with $c=4$, $m=2$ and the connectivity of organ shapes to these 3-D images, the tissue volume data of interest is shaded by the volume rendering.

Composite 3-D display of head, brain, white matter, CSF, basal ganglia and blood vessels are calculated. Fig.3 (a) consists of head, brain and CSF. This 3-D display shows a synthesis of each 3-D display of head, brain and CSF. Fig.3 (b) consists of brain and blood vessels. The volume data of blood vessels is extracted from MRA images. The information of blood vessels is combined with the brain information.

5. CONCLUSIONS

We use 4-channel MR images of the same anatomical section to improve the accuracy of tissue extraction. The extraction method consists of a mixture of 3-channel MR images, the fuzzy c-mean clustering on the mixed images and check of the object-connectivity. Shading uses volume rendering. The shading model was improved to realize interactive 3-D display.

T1-weighted images, T2-weighted images, PD-weighted images and MRA images of human brain are analyzed numerically. A complicated discrimination of white matter, gray matter, CSF, blood vessels, and their spatial relationships can be recognized. The effectiveness of the proposed 3-D display method can be demonstrated for diagnosis and surgical planning.

Currently, we are extending the 3-D display method to a practical recognition support system.

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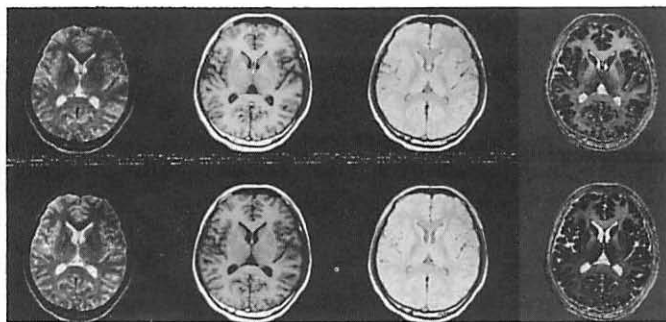


Fig.1 A nonlinear combination of three-channel MR images (T2-weighted images, T1-weighted images, PD-weighted images and nonlinear combined images).

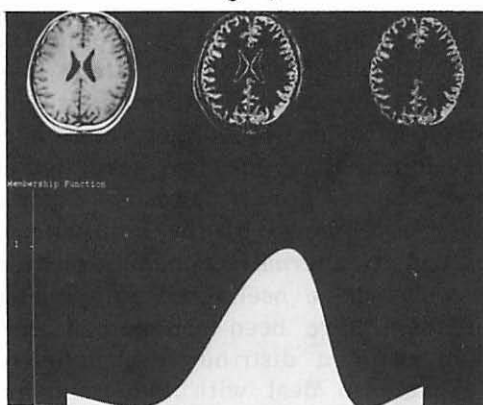
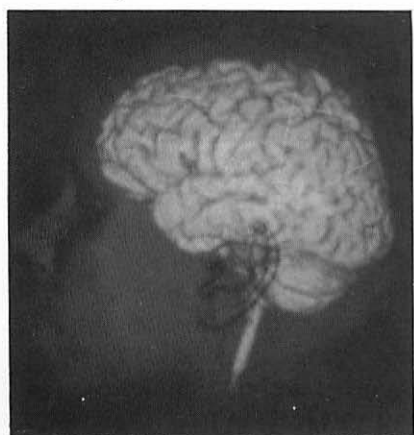
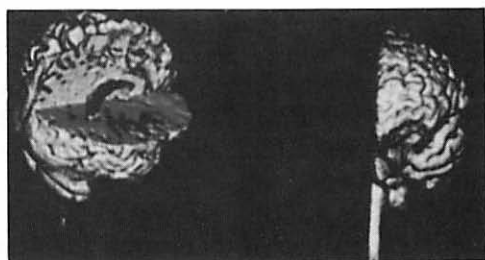


Fig.2 Extraction of an organ shape (top left: MR image, top center: a cluster image, top right: an organ image, bottom: image values and cluster values).



(a)



(b)

Fig.3 3-D display of brain structures

Image Fusion of Digital Radiograms and Bone Scintigrams

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I. Introduction

The number of imaging modalities has rapidly increased over the last decade and specific diagnosis of a patient is often based on different and sometimes contradictory informations gained by different modalities. A lot of specific analysis, interpretation and visualization tools have been developed since the late seventies in the realm of medical imaging^{4,5,6}. Some groups already reported on possible benefits, which might be obtained by the simultaneous representation of information provided by alternative imaging techniques^{1,2,3}. Most of these systems however have been used for experimental purposes and only a few of them have been commercialized⁶. Therefore we started the development of a distributed visualization and analysis system, which is capable to deal with two- and three-dimensional imaging modalities including the application of method oriented processing tools as well as image fusion techniques.

So far, the most work has been done within the field of the management of complex image data (CT, MRI, PET). Applications are so far restricted to special cases. The number of possible applications for superposition of images might probably increase, when plain x-ray examinations and planar nuclear scans could be easily combined.

One promising field is the evaluation of the skeletal system. In many cases the referring clinician asks for both radiography and bone scan. Often, however, findings of one or both modalities are normal, equivocal or difficult to interpret. While the radiogram offers excellent morphologic information nuclear medicine can contribute data about the functional status of the organ in question for the price of smaller spatial resolution. In this way these two imaging modalities complement each other in an ideal manner and one can expect, that a combination of the registered images would probably provide additional information not apparent in one image alone¹.

In this paper we present our first experiences with the combination of radiographs and isotope bone scans of the vertebral column. The described software tool was entirely developed in 'C' and is a part of our visualization and image processing system.

II. Methods

a. Image acquisition

Digital radiograms are acquired utilizing a DIGISCAN (Siemens Co.) computed digital radiography system. Spatial resolution depends on film format and reaches about 2 to 3 lines/mm. The matrix size is about 2000 x 2000 pixels with 12 bit greyvalue encoding.

Bone scans are recorded after the injection of about 600 MBq of Tc-99m-DPD with a standard gamma camera (i.e. MaxiII [GE], ZLC75, Orbiter [Siemens]) fitted with a standard, parallel hole, high resolution collimator. The gamma Camera is either connected to a gammall or a microVax computer system, where the digital images can be stored. The matrix size for nuclear scans is 128x128 pixels.

b. Patient positioning and markers

Both x-ray and bone scan images are acquired with the patient lying in either supine or lateral position. In order to allow matching of corresponding images during postprocessing two markers are fixed to the skin of the patient. As a marker served a small plum ball, which was identified on the nuclear scan using a Cobalt 57 source.

c. Image transfer

Images of both modalities are transferred via tape. In the near future a network connection to the department of nuclear medicine and the radiologic department will be constructed.

d. Postprocessing

The development of the presented software program was performed on two hardware components: A CONVEX 220S computer with 2 parallel processors and 128 MB memory and a SGI workstation

with 48 bitplanes for double buffered visualization and a resolution of 1280*1024 pixels. Both computers are connected to a local area network. Using the Distributed Graphics Library (TM of SGI) both machines can share the workload resulting in a better performance of the complete system.

The visualization and image manipulation system is entirely written in 'C' with the support of the Distributed Graphics Library. The basic principles of the implemented software system are:

- unique file format for all imaging modalities adapted to the ACR-NEMA SPI protocol.
- easy user interaction via mouse using file browsing and pull down menu techniques.

Meanwhile the system has also been implemented on an IBM 6000 RISC station, which is compatible with the SGI Distributed Graphics Library Standard in a clinical setting.

e. Image display and fusion

After the selection of the digital radiogram and the corresponding nuclear scan both images are displayed in their original resolution side by side on the screen. If the user selects to perform image fusion, he is asked to mark corresponding points (regularly 2) on both images. These points can either be markers placed on the surface of the patient or anatomical landmarks, which can be clearly identified on both images (fig 1). The image fusion of different images is based on the following preconditions:

1. The patient must be positioned identically on both imaging modalities.
2. The geometry of the different images must be comparable.

Based on the general coordinate transformation matrix the coordinates of the first image with the lower resolution are transformed to the coordinates of the second image.

As in most instances pathologic changes in nuclear scans show an increased uptake this information is filtered by selecting a suitable threshold in order to suppress 'normal tissue'. A low pass filtering process of the resulting image suppresses noise and disturbances. After

coordinate transformation this image is superimposed to the digital radiogram. In order to combine both images we chose an arithmetic operator (fig 1).

III. Results

We found that with the proposed technique the accuracy of image fusion is sufficient for identifying the site of pathologic uptake on the digital radiogram. Accuracy is in the range of the spatial resolution, which can be obtained with planar scintigrams.

Due to our limited number of patients so far exact data concerning possible improvement of diagnosis can not be given yet. However, there is strong evidence, that this technique will lead to stronger confidence in the findings of both imaging modalities.



fig 1a

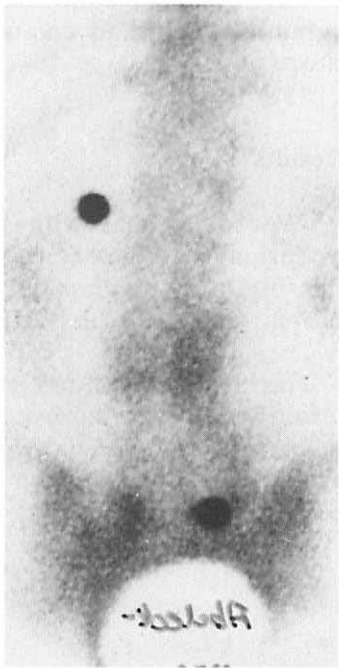


fig 1b



fig 1c

Fig 1a-c: Patient with Spondylodiscitis
a. original digital radiogram,
b. original bone scan
c. combined image

IV. Discussion

The proposed design of a combined presentation of X-ray images and nuclear scans is easy to handle and requires no refined skills in computer techniques. This software tool is integrated in a larger program environment, which offers further instruments for image display and processing.

In contrast to the technique proposed by Hawkes et al.¹, with which x-ray and bone scans are transferred to the same low matrix size, we have the possibility to display high resolution digital radiograms side by side with the corresponding nuclear scan. Thus there is no loss of information, when looking at the original images. Only for the purpose of image fusion a matrix reduction is necessary.

One effect of combined presentation of images from different modalities could be an increase of sensitivity and specificity.

Moreover this kind of image presentation will find great acceptance among clinicians. They often have to face different or even contradictory reports from radiologists. Very often they have to interpret these reports themselves and must come to a final conclusion. Why shouldn't we do this job for them? With further spreading of networking within hospitals and even outside we will be able to provide them with extraordinary images and a definite description and interpretation of the observed findings.

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Performance on Detection of Pulmonary Nodules on a High-Resolution CRT-Display

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Since the first use of X-ray images in medicine the method of working with these images (concerning image-formation, image-viewing and image-archiving) hasn't undergone any major changes. The quality of the X-ray images has been improved during these years and new technologies have been added increasing the number of image modalities considerably. Some of these new technologies have been developed on the basis of a computing system. They have been introduced as a complete system to the medical department producing digital images. Now, there exists the demand for merging all existing image modalities together into one concept of a Picture Archiving and Communication System (PACS) where physicians can have access using image workstations. Most of the technical problems associated with introduction of a PACS are solved or solvable, but an important point for the integration of these systems is the ability of reaching the same or a better diagnostic accuracy. The bottleneck is the "quality" of the display of the viewing workstation. The problems monitors have are wellknown, they are limited in spatial resolution and, the more important point, they are limited in brightness and contrast.

For evaluating the possible diagnostic accuracy this study chose one of the most difficult tests, the detection of pulmonary nodules. This test affords a good spatial resolution, but also a good contrast according to the wide exposure range of chest X-rays.

Materials and Methods

The image set of this study consisted of 120 conventional p.a. chest images, obtained under the same exposure conditions with 125 kVp, a FFD of 2.00 m and automatic exposure timing. To lower contrast a film with a large latitude (Eastman Kodak TMAT-L) in combination with a hilus filter (DuPont) was used. 60 radiographs showed no pathologic findings. In each of the remaining 60 radiographs a single pulmonary nodule was artificially created using silver nitrate solvent, a method described in detail by Vassallo et al. [VASSALLO 1989]. This artificial nodules cannot be differentiated from true nodules and

have the advantage of obviating a gold standard. The conventional films were digitized with a drum laserscanner (DuPont). The matrix of the images was 1648 x 2048 pixel x 12 bit, corresponding to a pixel size of 210 microns. As CRT-display a monitor with 2560 x 2048 pixel x 8 bit (Megascan) in connection with a special console and workstation for organizing and manipulating the images was used. This workstation was specially designed for reporting and reaches with a special bus structure very fast access to the images [DAHM 1991]. Possible functions for image manipulation were windowing, leveling and zooming. An attempt to diminish the known disadvantage of the low contrast on the CRT-display is histogram equalization. Therefore the four observers (all experienced radiologists) read the images in two variations, first unprocessed and second histogram equalized. For comparison the images were also read on a conventional lightbox. There was no time limit for reporting, classification was done in five classes (1 = definitely nodule, ..., 5 = definitely no nodule). Data analysis was done using ROC-methods (Feasible, BAZIS).

Results

First the characteristic of the display was measured. The brightness of the monitor as function of the greyvalue correlates well with human subjective visual perception of brightness. The Megascan monitor works in the range between 0 and 130 candela, a conventional lightbox displays up to 5000 candela.

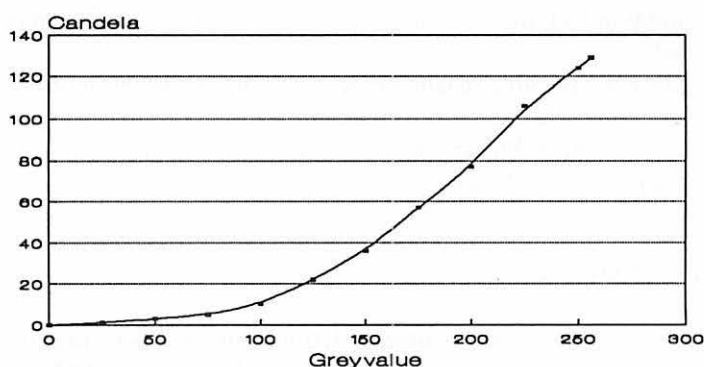


Figure 1: a) Characteristics of the Megascan Monitor

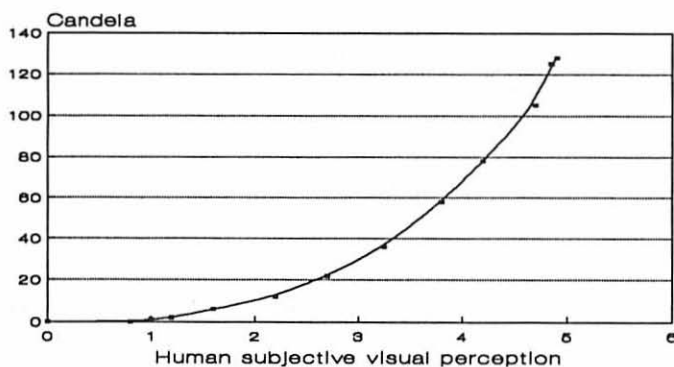


Figure 1 b) Human subjective visual perception of brightness

The ROC-Curves were calculated for every observer individually and for the four observers together.

The ROC-curves for the four observers and the areas under the curve for the film, the viewing station and the viewing station with histogram equalization are shown in figure 2.

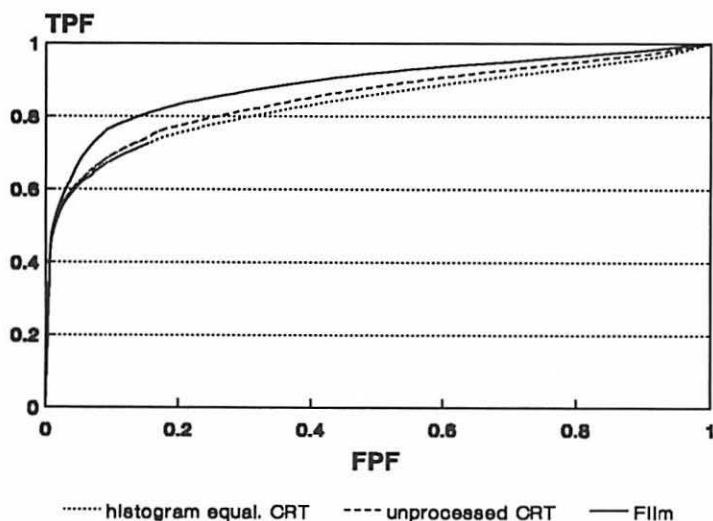


Figure 2: ROC-curves and AUC for the four readers of film (0.912 ± 0.044), digital unprocessed (0.853 ± 0.023), digital histogram equalized (0.837 ± 0.043)

There was a significant decrease ($p < 0.05$) in performance in the detection of pulmonary nodules for the viewing station compared with conventional film, although the interobserver variance showed reader with a better performance on the digital system than one on conventional film based system. There was no significant difference in performance between unprocessed and histogram equalized images.

In comparison to previous studies using CRT-displays with 1024^2 matrices the AUC's of this study showed a significant increase in diagnostic accuracy using Megascan-displays. However the performance of a conventional lightbox was not completely reached.

Table 1 shows the results of other studies, which point out similar results.

The time used for reporting was increased from 31.6 ± 5.69 sec for conventional film to 46.2 ± 11.9 sec for the unprocessed images shown on the CRT-display and to 40.8 ± 5.42 sec for the histogram equalized ones. The difference between film and CRT was significant ($p < 0.05$), between the two different presentations on the CRT there was no significant difference.

	Film	1024	2048
Hayrapetian et al. 1988	0.73		0.75
Wiesmann et al. 1990	0.92	0.76	0.75*
Ackermann et al. 1991	0.96		0.87*
this study	0.91		0.84

* = 2048 matrix displayed on 1024 matrix

Table 1: Comparison with other studies. The AUC of this ROC-studies are shown. Only Hayrapetian et al. evaluated a 2048 x 2048 pixel monitor, the other uses 1024^2 displays.

In figure 3 the resulting AUC for the CRT-display are shown versus the time needed for establishing the diagnosis for every reader. A decrease in diagnostic accuracy is demonstrated for reporting times below 40 sec, which is caused by insufficient time spent for windowing.

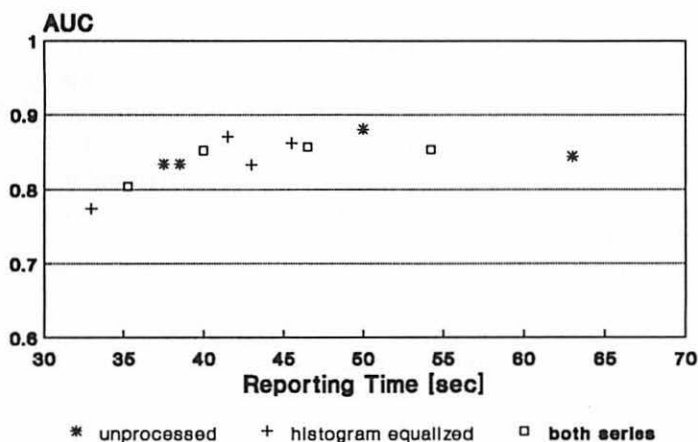


Figure 3: AUC vs. Time needed for diagnosis

Conclusion

The increase in diagnostic accuracy using a CRT-display with 2048 x 2560 pixels compared to displays with a 1.024 or smaller matrices points out the necessity using a high resolution display for reporting. The inferior performance on CRT compared to conventional image interpretation may be explained by different aspects e.g. artefacts from the laserscanner might influence diagnostic accuracy.

The main problems when reporting radiographs on a CRT-display are the lower brightness and contrast. To get equivalent or better performance on the CRT the contrast must be optimized. This can be done automatically by image processing (e.g. adapted histogram equalization) or manually by the observer using window and leveling. It is shown that it is very important to use window and leveling. In our opinion an extended use of these standard tools may increase the diagnostic accuracy significantly, but this causes also an increase in reporting time.

To increase diagnostic accuracy on CRT-displays image processing is of great importance and should be further evaluated.

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3-D Solid Model Reconstruction From MR Images for Surgical Approach

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INTRODUCTION

MRI and CT data provide 2 dimensional images for medical diagnostic purpose. Although inadequate in comparison to the true 3-D mode images, 3-D reconstructed projectional images made from tomograms have improved the diagnostic ability of the radiological imaging systems. The recent leaps in the 3D technology has attracted the prospect of using the principle in diagnosis of complex anatomical variants. The purpose is to provide a better visual perception from angles previously deemed to be almost impossible. Though the images produced show superiority in all dimensions from the previous 2Ds, there is still a great demand from the professionals who would prefer improvement in terms of contour, contrast and edge smoothing. The demand for a 3D solid model is also very high. Such models can provide total visual and tactile perception of the anatomy and its variant in a diseased individual. Above all the procedure would be non-invasive or almost non-invasive depending upon the modality of the primary investigation.

A limited number of experiments have focused on the importance and the applicability of the solid model reconstructions from MRI or CT. We experimented with such types of data in creating models for better clarity, multiple angle views and total tactile perception of the anatomical aberrant. The technique was aimed to help the radiologist provide a more precise report about and of the appearance of the aberrant organ. It is also aimed to create a pre-surgical simulation for the surgeons to see beforehand what they will expect to encounter during the operative procedure.

To reflect the advantage of displaying a complex anatomy and its aberrant we chose the aneurysm of the carotid artery from a patient in our ward. A second experiment with another patient who had been suffering with a Glomus Jugular tumour

was selected. Volunteers with normal anatomy of those region were selected as control.

MATERIALS AND METHODS

MR angiography provided the data for the model. The FISP3D sequence was used with a matrix size of 256x256. The total number of slices were 64 of 1.5 mm thickness. The scanning was performed on Siemens Magnetom 1.5 Tesla scanner.

We chose the laser lithography in reconstructing the solid models. The lithograph is easier to operate, comparatively small in size and produces no hazardous residue. The process used for constructing the 3-D models is to solidify liquid photopolymer selectively using the light energy. Since the light energy produces its effect only on the surface of the material, the solidified portion of the material looks like a layer. By repeatedly forming the layers the solid model was reconstructed. This method has some advantageous characteristics in comparison to the ordinary methods e.g, chipping a solid material to make a model.

1. It is possible to make a model with complex internal structure.
2. It consists of simple and cost effective software and hardware which is regulated in only two and a half axis.
3. Since this is an untouched procedure and there is no need to change worn-out parts, it can be left alone to produce the model overnight.
4. The device makes no noise, vibrations and produces no scraps.

Procedure

The model making procedure is divided into the following steps---

1. Image Processing

The CAD software "Pro-Engineer" was used to create the image on the computer screen from the MRI data. The software manages the reconstruction in two steps---

a) EXTRACTING VESSELS FROM MRI-

The threshold method was used to extract by selecting the whole area in which the signal intensities are within the dynamic range of the signal of the vessels. Then the edge image was calculated by using the MARR-HILDRETH OPERATOR. Finally, a 3-D search was made starting from the trunks of the extracted vessels and proceeding

towards the edge.

b) RECONSTRUCTION OF THE VESSEL IMAGES-

The Triangle Patched expression was employed for a smoother form of reconstruction. First the quantized noise arising from the roughness of the resolution of the original image was removed. Next, by using the improved Christiansen method the smooth outlines were reconstructed

For better stability and accuracy some assistant data were added to the CAD data before the model was created on the lithography. These data are of two types --

i. CAD Data Modification

It is used to set up the --

- a) number of models made at each instance
- b) the position of the model
- c) the ratio of magnification and reduction

ii. Scanning Locus Modification

This added assistant data to the contour lines computed from the CAD data for more precise accuracy.

2. Layering

After defining the model on the computer it was divided into axial slices of equal height. Data from each of these slices were fed into the lithograph beginning from the lowest layer. As each layer of photopolymer formed the polymerizing reflex firmly adhered adjacent layers to each other. The function continued till the topmost layer was formed and the polymerised resin took the form of the selected image. The vessels kept their 3-dimensional relations intact in terms of tortuosity and position as the branches are supported by props of polymer. To enhance the visualization, the vessels were dyed red.

CASE REPORTS-

CASE I:-

A 70 yrs. old female was admitted with right visual acuity loss. On clinical examination a ptosis of the same eye was observed and the 3rd nerve palsy was demonstrated. On angiogram right carotid artery giant aneurysm was detected.

CASE II:-

A 72 yrs. old female was admitted with the complaints of tinnitus in the right ear. No gross physical findings were found on examination. MRI and CT revealed the Glomus Jugular tumour with bone destruction. MR angiogram displayed the

vasculature of the tumour.

RESULTS

In both cases the lesion was evident on contrast enhanced MRI scan. CASE I had an aneurysm arising from the carotid artery and on MIP (Maximum Intensity Projection) the structure was observed within the tortuosity of the vessels. This made visibility limited and the root of the aneurysm was difficult to see from the orthogonal views of the MIP. The solid model clearly outlined the aneurysm and the vessels and the relationship to each other. Since the reproduction scale was equal to that of the original scan, appreciation of the size and shape of the lesion could be made directly from the model. CASE II had a more complex anatomical aberration. The tumour vessels were difficult to see on the MR images. From this study the final model displayed clearly the relationship of the tumour vasculature in comparison to the normal vessels.

DISCUSSION

The first model produced better spatial visualization of the complex shape of the blood vessels leading to an improved understanding of the relationship of the aneurysm to the surrounding structure and to the root of its origin from the vessel. Previously non-invasive measurement techniques producing 3D images of arteries were performed on the carotid and its bifurcation by ultrasonography but our experiment deals with the more tortuous and complex branching of the carotid and the circle of Willis with MR Angiography. The second model was constructed to display that anatomical variants which are difficult to visual and to approach surgically, are better understood with a 3-D solid model reproduction. The most important aspect of these 3-D models lie in their quantitative abilities. The models had been able to provide 3-D measurements, appreciation of the organ surfaces and display the interrelationship of the adjacent organs. The solid model helps the diagnostician to examine the structure from all angles depending upon his choice. With these quantitation we can characterize the deformity, measure the effect of the growth and can build a method of predicting the outcome of the surgical intervention. It also provides an unique opportunity for neuroradiologists and neuro-surgeons who are keenly interested in visualizing brain structure and

intracranial vessels in an integrative manner . As the brain structures can also be reproduced by a slight modification of this experiment and then integrated manually. In the final stage, this procedure may be used as a surgical pre-planning tool allowing a surgical rehearsal prior to the actual operation. The procedure takes a total of 24 hrs. starting from the MRI scan up to the reconstruction of the model. But with the improvement of the MRI scan techniques and with the development in the design of the lithograph; it is possible to reduce the time to a more suitable limit. To display the structure in the original inclination the vessels are propped up on stilts of polymer which may make it difficult to transport the model to another hospital because of its fragility. Other than the present difficulties in MR scan the procedure offers a lucrative and realistic alternate to the onscreen 3D images.

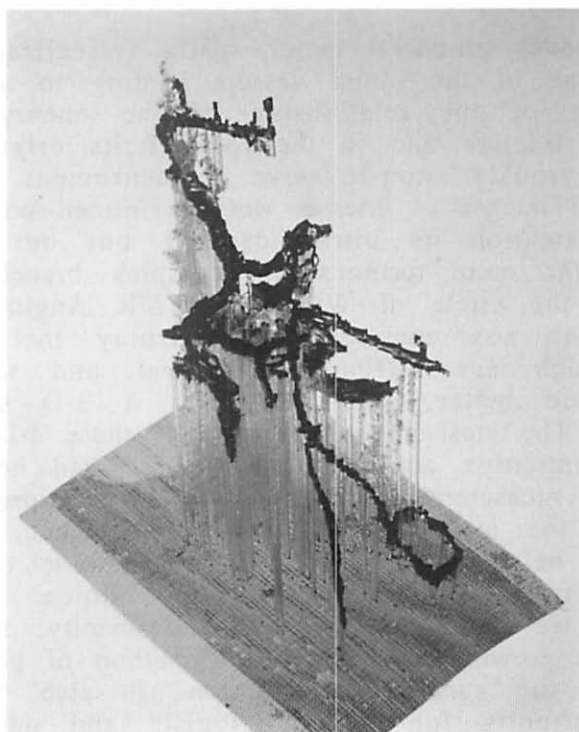


Fig. 1, 3D model of the normal anatomy of the Circle of Willis

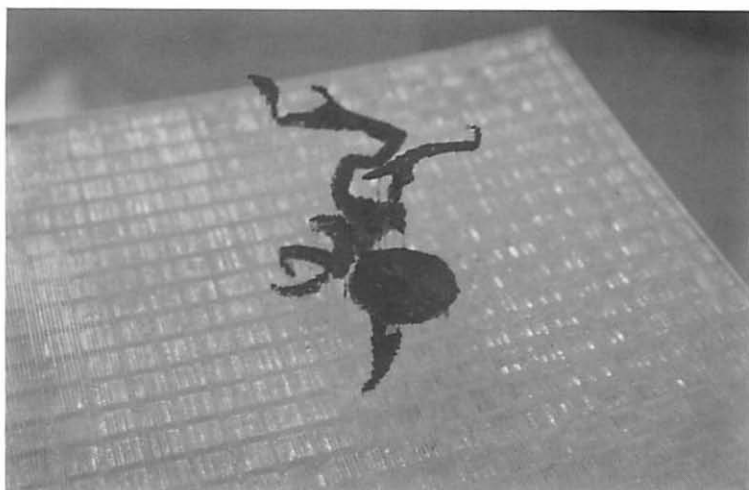


Fig. 2 , 3D model of the aneurysm showing the relationship to the Circle of Willis



Fig. 3, 3D model of the vasculature of the Glomus Jugular Tumour

SESSION 4

**Public Health Service
Applications**

Chair: Mary Anderson

Computer-Assisted Radiology: Research Support in the Diagnostic Imaging Research Branch, National Cancer Institute

Faina Shtern and Wendy R. Fredericks

Diagnostic Imaging Research Branch, Radiation Research Program, Division of
Cancer Treatment, National Cancer Institute, Bethesda, MD

The Diagnostic Imaging Research Branch (DIRB) was formed in 1982 as an extramural, research-supporting organizational unit at the National Cancer Institute (NCI). Since that time, DIRB has acquired a leading role in imaging science support at the National Institutes of Health. The mission of the DIRB in imaging science is two-fold: 1) management of investigator-initiated grants; and 2) development of national policy in imaging science.

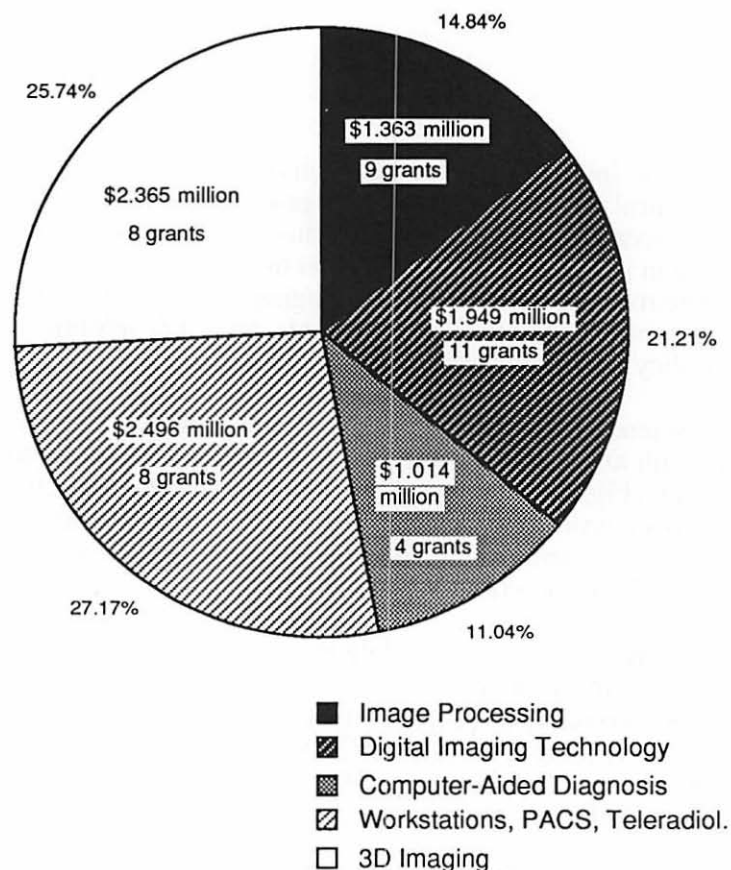
Computer science comprises a substantial part of the DIRB grant portfolio, with annual support of \$9.2 million, (or 23% of the total 1991 budget) (Fig. 1). Supported computer science areas include 3D imaging (26%), workstation design and picture archiving and communication systems (27%), digital radiography (21%), image processing (15%), and computer-aided diagnosis (11%).

The high priority assigned by the DIRB to computer-assisted radiology is also reflected in the development of science policy. In this paper, we will describe two research programs that have been developed by the program staff: 1) three-dimensional (3D) imaging-based tumor volumetric analysis; and 2) development of digital mammography and related technologies.

QUANTITATION OF TUMOR RESPONSE TO TREATMENT: A THREE DIMENSIONAL APPROACH.

Changes in tumor volume in response to anti-neoplastic treatment constitute important criteria for the evaluation of therapeutic efficacy in cancer patients. Reliable quantitation of changes in tumor volume is of great importance for detecting biologic activity of the administered therapy in individual patients. It has also been pointed out that **"the ability to compare results of clinical trials depends upon consistent definitions of tumor response and the use of reliable and reproducible methods of tumor**

**Computer-Assisted Radiology Research Supported
by the Diagnostic Imaging Research Branch,
National Cancer Institute in Fiscal Year 1991**



Total Computer-Assisted Radiology Research
Supported by DIRB in FY91 = \$9.2 million

Total DIRB Grants Funding in FY91 = \$40.1 million

Figure 1

measurements”(1). Generally, clinical investigations in oncology depend heavily upon two-dimensional radiologic techniques to determine tumor response to treatment. The major focus of this proposal is to optimize mathematical analysis of tumor volume based on 3D radiologic images in order to enhance evaluation of therapeutic efficacy of various treatment modalities/regimens in cancer patients and to facilitate comparison of clinical trials.

While the role of diagnostic imaging modalities in detection and delineation of neoplasms has been extensively studied, a fully adequate approach to serial evaluation of tumor response to treatment has not been developed. Until the present time, it has been difficult to obtain accurate tumor measurements, and volumetric analysis of tumor response to treatment has been usually subjective and qualitative rather than quantitative in nature. Indeed, errors in tumor measurements have been included among the major factors limiting the interpretability of response rates(2). Major limitations in the accuracy and reliability of tumor measurements stem from the two-dimensional nature of imaging data display currently used for tumor volume analysis. Tumor response to treatment, however, is a complex three-dimensional phenomenon, and the use of two-dimensional imaging techniques is frequently inadequate for its full evaluation. The DIRB workshop entitled “3D Data Display and Analysis for Cancer Treatment Planning” (July, 1990) confirmed the need for accurate tumor measurements in oncology and concluded that a 3D approach is optimal for serial volumetric tumor analysis.

At the DIRB workshop, the state-of-the-art in 3D imaging research in oncology was examined, and future research directions were discussed and prioritized. This workshop demonstrated that 3D imaging can provide unique information for spatial tumor display and tumor volumetric analysis, which cannot be obtained by any other means. Further, the participants agreed that there are two closely intertwined basic scientific areas of highest priority to the future advancement of tumor volumetric analysis: 1) automated “segmentation”, or “tumor delineation”; and 2) multimodality image “registration”, or “superimposition” (e.g. CT, PET, conventional and metabolic chemical shift MRI, immunoimaging).

Special emphasis has been placed on the need to develop automated image segmentation in contrast to currently used manual delineation of tumor margins in order to facilitate the process of measurement and to minimize errors. Utilization of machine intelligence was identified as one of the promising potential avenues for the advancement of automated “tumor delineation”. Another research area which has been

identified as an area of major importance for the field of 3D image analysis is multimodality image registration, the specific goal of which is to combine high resolution anatomic information provided by such modalities as CT and proton MRI with biologic/metabolic information obtained from PET, conventional Nuclear Medicine, immunoimaging, multinuclear MRI/MRS, and other modalities. Scientific advances in multimodality image registration may result in improved diagnostic specificity as compared to a single modality approach to tumor imaging and, consequently, it may become possible to differentiate foci of viable tumor from (and/or within) scar, necrosis, edema, inflammation and other processes. Thus, advancements in multimodality image registration are expected to improve specificity and accuracy of tumor volumetric analysis.

The specific goal of this proposal is the development and optimization of a quantitative analysis of tumor response to treatment based on 3D medical imaging. The proposed research will stimulate the achievement of optimal tumor volumetric analysis by means of the development of advanced approaches to two critical basic computer science topics, automated image segmentation and multimodality image registration, and their validation and testing. This RFA is expected to support three or four R01 grant applications in the area of volumetric tumor analysis. This proposal if funded would offer the potential of improved clinical management and would facilitate the development and evaluation of anti-neoplastic drugs and other treatment modalities in cancer patients.

NATIONAL DIGITAL MAMMOGRAPHY DEVELOPMENT GROUP

The goal of this proposal is to stimulate research in the area of digital mammography and related technologies in order to improve breast cancer detection and staging. The scope of the proposed research will encompass technologic developments in digital mammography integrated with basic research in critical avenues that can be opened by digital mammography, such as image processing for improved lesion visualization, computer-aided diagnosis for enhanced image interpretation and teleradiology, or electronic image transmission, as a potential mechanism to bring world expertise to community hospitals. In order to achieve the above-stated goals, the National Digital Mammography Development Group (NDMDG) will be established to ensure comprehensive collaboration between industry (e.g. design of receptor or display systems), the academic community and the NCI for an integrated, multi-component approach to digital mammography development. NDMDG will be supported by the interactive R01 mechanism (as described in the NIH Guide for Grants and Contracts,

January 10, 1992) and will consist of six major components (R01s): 1) digital mammography; 2) image processing; 3) computer-aided diagnosis; 4) teleradiology; 5). pre-clinical and clinical technology evaluation; and 6) Headquarters for the scientific leadership (centralized development of experimental design and data processing).

The major thrust of this proposal is to facilitate integrated technologic development of digital mammographic systems. This program announcement encompasses a full range of studies from basic technology and instrumentation development through their pre-clinical and clinical evaluation. The research agenda for the National Digital Mammography Development Group encompasses the following goals:

1. To develop and evaluate new technologic advances in order to increase image quality in digital mammography (e.g. spatial/contrast/time resolution) (3,4);
2. To develop and validate new digital imaging methodology (dynamic, or "real time" imaging);
3. To develop and validate new image processing techniques for increased lesion conspicuity;
4. To develop and validate new algorithms, neural networks and other forms of machine intelligence for CAD (5,6); and
5. To develop and validate practical methods of data compression, storage and image transmission for tele-mammography (7).

In summary, DIRB has been actively supporting research in computer-assisted radiology.

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Computer-Assisted Radiology Research in the Center for Devices and Radiological Health

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The Division of Electronics and Computer Science of the Center for Devices and Radiological Health (CDRH), FDA carries on a small but significant program of research on the evaluation of medical imaging technologies. Much of this research has a direct bearing on computer-assisted radiology, focusing as it does on a quantitative understanding of imaging performance evaluation and on the distinction between information detected by an imaging system and the coupling of that information to the human observer.

The revolution in computing technology of the past two decades has brought with it a revolution in imaging systems, with MRI, CT, and SPECT probably the most prominent examples. This explosion of imaging technologies brought an urgent need for imaging performance assessment methodologies to quantify, optimize, and compare performance. CDRH scientists have played a key role in developing these methodologies--to the point of acceptance by the scientific community, and codification in a draft ICRU report. The scope of these efforts can be inferred from references 1-10.

Investigation of ultrasound tissue characterization is an example of ongoing research directly related to computer-assisted radiology. CDRH scientists, in collaboration with clinical investigators, have been studying the diagnostic information available in ultrasound images.¹¹ "Textural" information is

generally not directly interpretable by the radiologist; however, it can be of critical importance for the classification of such conditions as diffuse liver disease. CDRH work in this area adds considerable weight to the argument for benefits for radiologists in computer processing of images and the provision of "parametric" images to bring out information that would otherwise go unnoticed.

Research on the fundamental nature of the image reconstruction process is another example of a current CDRH research project related to computer-assisted radiology.¹² Reconstruction itself is the prime example of the computer's ability to turn otherwise uninterpretable raw data into an image suitable for viewing by a radiologist. CDRH scientists are engaged in collaborative research to discover the fundamental limits on reconstruction, including such questions as how much such prior information as positivity can assist in the reconstruction process.

The overall thrust of CDRH imaging research is toward the objective quantification of imaging performance, both in the ability of imaging systems to detect clinically relevant information and in the ability to transfer that information to the radiologist. Such measures of imaging performance are vital to the development of computer-assisted radiology.

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The Visible Human Project of the National Library of Medicine

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The Visible Human Project has its roots in a 1986 Long-Range Planning effort of the National Library of Medicine (NLM). As a result of the deliberations of consultants in medical education, the long range plan recommended that the NLM should "...thoroughly and systematically investigate the technical requirements for and feasibility of instituting a biomedical images library." It encouraged the NLM to consider building and disseminating medical image libraries much the same way it acquires, indexes, and provides access to the biomedical literature. It foresaw a coming era where NLM's bibliographic and factual database services would be complemented by libraries of digital images, distributed over high speed computer networks and by high capacity physical media. Not surprisingly, it saw an increasing role for electronically represented images in clinical medicine and biomedical research.

Early in 1989, under the direction of the Board of Regents, an ad hoc planning panel was convened to explore in-depth the proper role for the NLM in the rapidly changing field of electronic imaging [1]. After much deliberation, the NLM Planning Panel on Electronic Image Libraries made the following recommendation: "NLM should undertake a first project building a digital image library of volumetric data representing a complete, normal adult male and female. This Visible Human Project will include digitized photographic images for cryosectioning, digital images derived from computerized tomography and digital magnetic resonance images of cadavers."

The technologies needed to support image libraries, including high bandwidth communications and increasingly high resolution representations are new and are evolving rapidly in a number of disparate directions. Although standards for picture libraries on analog videodiscs are established and accepted, there are few if any standards for storing image data in digital pixel libraries or for the capture and display of such data. Software requirements are site specific and are based on the available hardware configuration. All this makes the sharing of image pixel libraries a difficult problem. In addition, the classification of objects within pixel images to produce geometry-based graphics will require standards for the

linking of semantic (text-based anatomical terms) to the sets of geometric primitives from which those anatomical objects can be rendered graphically.

In view of these findings, the Planning Panel made some further recommendations: that NLM begin the collection of data for the Visible Human Project; that we establish standards for acquisition and computer representation of this data; that we initiate a research effort to develop methods, tools and standards for the classification of objects within anatomic image data; that we expand upon the initial image library composed of normal structure, to encompass specialized image collections which represent related structural information (e.g., disease-oriented image collections, normal growth and development of body systems); and that we encourage investigator-initiated research into methods for representing and linking spatial and textual information, which is becoming known as structural informatics.

The first part of the Visible Human Project is the acquisition of transverse CT, MRI and cryosection images of a representative male and female cadaver at an average of one millimeter intervals. The corresponding transverse sections in each of the three modalities are to be registered with one another.

A contract for acquisition of the pixel-based data was awarded in August 1991 to the University of Colorado at Denver with an expected completion date September 1993. Victor M. Spitzer, Ph.D. and David G. Whitlock, M.D., Ph.D. are the principal investigators. The data acquisition contract for the Visible Human Project requires that a "normal" and "typical" male and female cadaver be acquired. CT scans at an average increment of one millimeter of the entire body and corresponding MRI scans of the head would be obtained.

The cadavers will then be cryosectioned transversely at intervals which correspond to the CT and MRI images already obtained. Color photographic images will be taken at each slice level with two separate camera systems. A complete set of transverse cryosectional photographs should become available to the NLM in the fall of 1993.

Under the terms of the data collection contract, the cryosectional data will be returned to NLM as photographs of the cross-sections. But the goal of the Visible Human Project is a digital image library as well as a photographic archive. Towards the end of the summer of 1992, a second RFP will be issued for the digitization of the cryosectional photographs. That contract is to be awarded near the beginning of 1993, so as to be in place when any of the photographic pictures becomes available to the NLM.

The Visible Human data set will comprise approximately 42 gigabytes of pixel data (uncompressed), which would correspond to about 70 CD-ROMs. A

distribution format and media have yet to be selected. Preliminary meetings were held with representatives of the ACR/NEMA committee of the National Electrical Manufacturers' Association (NEMA) in order to explore the possibility of using this transmission format as an archival format under which the National Library of Medicine will distribute the pixel library. There appears to be no simple solution to this problem.

Once the pixel library is acquired and its mode of distribution is established, another part of the Visible Human Project will be initiated. A research effort, whose objective will be to develop methods, tools and standards for classification of anatomic image data, will be started. This will allow applications to be developed which can extract, manipulate, and display image subsets on the basis of organs, tissues, body systems, and biologic function. This part is projected to begin during the spring of 1994.

The larger, long term goal of the Visible Human Project is to produce a system of knowledge structures which will transparently link visual knowledge forms to symbolic knowledge formats. Methods need to be developed to link image data to symbolic text-based data which is comprised of names, hierarchies, principles and theories. Standards do not currently exist for such linkages. Generalizable methods like the use of hypermedia where words can be used to find pictures, and pictures can be used as an index into relevant text are being experimented with. Basic research is needed in the description and representation of structures, and the connection of structural-anatomical to functional-physiological knowledge. The goal is for the print library and the image library to become one unified resource for medical information.

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SESSION 5

Expert Systems/Teaching

Chair: Alan H. Rowberg

Multipurpose Image and Data Management System for Radiologists

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Introduction

During the course of routine film reading, it is frequently desirable to look up facts, references, or refer to images of proven cases to facilitate analysis of difficult or unusual cases. Unfortunately, such reference resources are often not readily available in the reading room. As a result, diagnostic decisions may be made without information which might allow more accurate or complete diagnosis. These issues stimulated us to design a database management system for clinical radiology which would allow rapid look-up of imaging facts, references, and images of proven cases. This system, known as *Magic* (Multiple Application Gnostic Imaging Computer system), is being implemented on a portable microcomputer to allow access to such information in any location. In addition to this primary purpose, this system serves as a convenient way for radiologists to keep track of interesting cases, slides, personal references, and frequently needed facts. The system also facilitates assignment of ACR codes.

Magic is comprised of multiple interrelated database files and was developed using a commercially available relational data base management system (4th Dimension, Acius, Cupertino, California).

Functional Description

Figure 1 shows the primary navigation screen. One can *lookup* or *add* to the database in the following categories.

- | | | |
|------------------------------|--------------|---------------|
| 1. Knowledge | 2. Cases | 3. References |
| 4. ACR Codes (look-up only). | 5. Questions | |

Knowledge refers to a broad array of knowledge types useful during clinical radiologic practice. This includes:

- | | | |
|---------------------------------|------------------------|------------------------|
| 1. Facts | 2. Normal values | 3. Finding discussions |
| 4. Differential diagnoses | 5. Disease discussions | |
| 6. Radiologic workup guidelines | 7. Statistical data | |

All these are stored in a single free-text field. A "fact-title" is stored as a separate

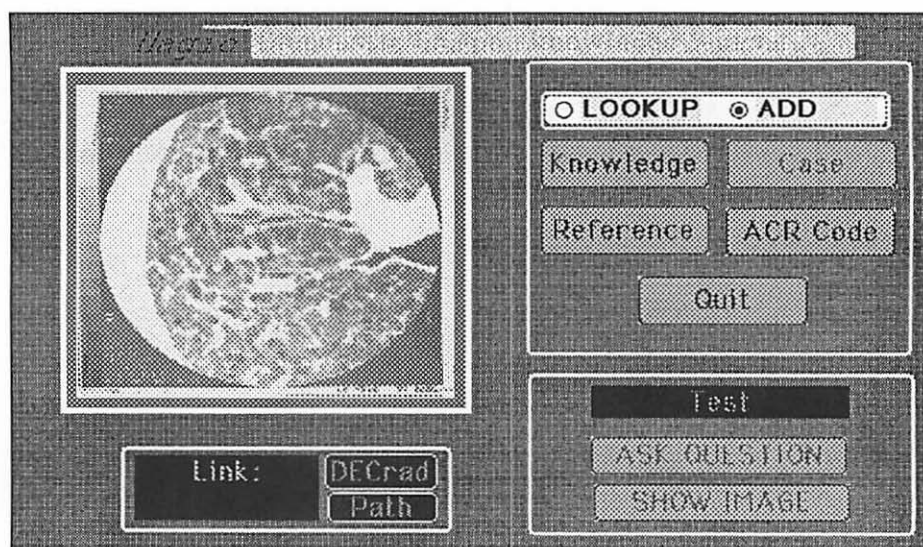


Fig. 1: Database Opening Options Screen

field, and its initial portion is used for indexing the table.

Figure 2 (below) is an example of the enterable data elements in the knowledge entry screen.

The knowledge elements may be dynamically linked to the reference database to allow linking of specific references which document the cited knowledge, or to

Entry for Knowledge

Title: Pericardial Thickness **Date:** 02/28/92

Organ: Heart and Great Vess **Modality:** CT

Disease Category: Normal

Descriptive Text:
Normal Pericardial thickness on CT is 1 to 4 mm. Distinguish..

Keywords (use @):
keyword
pericardium

ACR (use @):
ACRcode

<-Add
<-Delete

Reference Key	First Author	Title	Ref access

Questions:

Short title	Multiple Choice

Save
Delete
Cancel

Fig. 2: Knowledge Entry Screen

provide access to general reference citations to the knowledge in question. Each part of the *Magic* database is also linked to a *question asking* module (described below). Facts can also be associated with ACR codes.

Cases refer to specific individual clinical examples stored in the database. The case database allows storage and retrieval of individual images, or complete cases. The primary purpose of the case database is to provide a means of retrieving and displaying images from a digital archive. The system also permits the user to keep track of interesting cases where films may be stored in conventional film libraries, or personal teaching files. Interesting images from other sources such as slide collections, books, and journals may also be located in the *Magic* database. A link to radiology and pathology information systems is planned to allow look-up and storage of results.

Figure 3 (below) shows the first data entry screen in the case database. Associated fields include a descriptive case title, type of case (film, digital image, slides, book, journal), and image location. Specific identifying information is defined. Clinical history, index terms, ACR code, case discussion and references are provided for. Additional screens (not shown) allow for thorough description of image type (i.e. views, exposure factors, with/without contrast, imaging parameters, etc). Similarly, detailed description of image findings is provided for flexible retrieval of images based on image content.

The screenshot displays a software interface titled "CASE INPUT". The main area contains several text input fields and checkboxes:

- Case Title:** A large text field.
- Type:** Four checkboxes labeled "Film", "Slides", "Journal", and "Dig Image".
- Location:** A text field.
- Name:** Two text fields labeled "Last" and "First".
- MRN:** A text field with a "0" in the input area.
- Clinical History:** A large text area with a vertical scrollbar.
- Case Description:** A large text area with a vertical scrollbar.
- Index Terms:** A large text area with a vertical scrollbar.
- ACR Code:** A large text area with a vertical scrollbar.
- Case Discussion:** A large text area with a vertical scrollbar.
- References:** A large text area with a vertical scrollbar.

On the right side, there is a vertical sidebar with the following buttons and labels:

- Save** (button)
- Delete** (button)
- New Ref** (button)
- Key/Code** (label)
- <- Add** (button)
- <- Del** (button)
- Scan** (button)
- Text** (button)
- Image** (button)

At the bottom right of the main area, there is a button labeled **Link To Fact/Question**.

Fig. 3: Case entry screen

References are maintained separately in the database. Complete reference descriptors including the nature of the source document, author, title, full citation fields, user

supplied keywords, ACR codes and abstracts are provided for. The search engine allows for flexible reference searches by all fields. Each reference may be linked to other parts of the database including *cases*, *knowledge*, and *questions*.

ACR Code lookup and entry is provided in all entry screens. When the user types in an ACR code or part of it, the system automatically provides a lookup table of all the possible refinements at the next position of the code, with their full descriptions. The user can then select the code or codes to associate with a reference, fact, case or question.

Questions are maintained in a separate database table. Questions may be created for knowledge, cases, and references. This allows the system to operate in a self-test or query mode. In this mode, the user may define a subject area and the system will randomly playback previously stored questions in true-false or multiple choice formats. These questions can be created at the time of the original knowledge, case, or reference entry. After the user responds to the question, the original data element may be displayed. It is planned that images may be presented as questions or unknowns.

Technical Description

Magic is being developed on the Macintosh family of computers. We are specifically optimizing the system to run on a Macintosh PowerBook 170 portable microcomputer. In this configuration, an external monitor is required to display images. The database is implemented using the 4th Dimension relational database management system. Images are stored in PICT format and are independent of the database management system. 4D-Draw (MicroCad Corp.) is integrated into the database to handle image display.

Database Design

The characteristic features of such a database of medical knowledge are its heterogeneity and relational complexity. The types of data that are involved are of many different types and have complex many-many relationships. Thus a fact may be associated with several references, images, ACR codes or keywords and any of these, in turn may be associated with more than one fact. These are precisely the kinds of issues that are difficult for most database models to handle, and require a great deal of custom programming.

Two other hurdles to be faced in developing a system of this sort are 1) the seamless integration of images into the database and 2) development of an easy-to-use user interface.

From all these points of view we find that the choice of the 4-D relational database, with its drawing module 4-D Draw to be an excellent one. It allows point-and-click simplicity in designing relation between database tables (also referred to as files). We have implemented many-many relationships by interposing secondary linking files such as the *ref_fact* file (i.e. reference->fact) that provide a one-many relationship

images separate so that they can be used for other purposes, it was necessary to use the add-on program, 4-D Draw.

Discussion

Knowledge growth in radiology is occurring very rapidly and it is not possible for radiologists to know all that they should to practice state-of-the-art radiology in all of its many disciplines (1). Subspecialization has helped alleviate this problem, but much of radiology is practiced in areas where there is insufficient manpower available to allow subspecialization. We have been interested in using computers to deliver radiologic knowledge and images under expert system control. The expert system evaluates known clinical and radiologic data to determine clinical context and then retrieves images and factual knowledge that deal with relevant contextual issues (2,3). Because these systems are difficult to build, we were interested in finding other ways to provide computer-based access to clinically useful knowledge and images.

For the Magic database, we were specifically interested in building a database which would allow direct search for images based on findings, disease entity, and clinical values. Thus, for example, one might wish to view an example of the finding of enlarged retrocrural lymph nodes on CT regardless of etiology. Alternatively, one could search for findings of non-Hodgkin Lymphoma on abdominal CT. One could also restrict the search based on such clinical parameters as age, sex, presenting symptoms, etc. In the same way, we wanted to provide rapid access to knowledge which might be useful during diagnosis. For example, what is the upper limits of normal for the size of retrocrural lymph nodes? Or, what is the differential diagnosis of enlarged retrocrural nodes? Access to concise disease synopses was also felt to be important. The basic framework of the Magic database was designed to be able to handle these sorts of queries. While all of this information should ideally be available on-line, we also wanted to be able to incorporate images (and information) that might be readily available to the user off line. This includes classic images from the literature. Magic was originally conceived as a system that would be pre-loaded with domain information for the user like a textbook. We also wanted the user to be able to add information and images of his own. It was a natural extension of the basic system design to allow Magic to be used as a personal radiology data management system. In this way, it is possible to use this system to keep track of one's personal film-based teaching file, slide file, reference collection, etc. The relational nature of the database makes it easy to integrate and relate these various data elements.

Ultimately this kind of knowledge resource will best be available through departmental networks. Another, more immediately available alternative is to make such information available on a portable microcomputer. We have implemented the developmental version of Magic on a Macintosh Powerbook computer. Image access is not possible in this environment because of the limitations of the 1-bit portable display. We plan to install a suitable monitor in the CT reading area for image

display. Larger image databases will require additional outboard image storage.

We had previously participated in a collaborative project to develop a computer-based image learning library (DRILL project)(4). This effort involved definition of a comprehensive database structure for an image database including detailed field definitions for patient related data, examination specific data, detailed finding definitions (for mammography), image formats, and display tools. This ACR/NEMA compatible structure has been incorporated into several experimental systems, primarily in the field of mammography (5,6). Magic incorporates a similar relational structure to the DRILL database in regard to the retrieval of images by the findings contained.

The availability of powerful relational database engines for personal computers with graphical user interfaces and capacity to handle image display is extremely exciting. We believe that it makes possible the creation of "academic assistant" databases such as Magic that can hold different types of knowledge that can be easily accessed in the context of a clinical case or in order to write a paper or prepare a talk. This can be done without sacrificing the cleanliness and powerful search features of the relational model (unlike products such as Hypercard) and without the need for painstaking hand-crafting of knowledge interrelationships (as required in traditional expert systems).

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Application of Neural Networks for Improvement of Lung Nodule Detection in Radiographic Images

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ABSTRACT

An automatic lung nodule detection scheme using matched filter and artificial neural networks (ANN) has been developed. X-ray films were first digitized and match-filtered to obtain nodule enhanced images. Then, a searching algorithm was applied to locate suspected lung nodules on the digitized chest radiograph. Suspected nodule images were extracted as training data for neural networks. A program based on the above scheme has been implemented in a DEC 5000/200 workstation. The total processing time was less than 35 seconds. In this paper, both nodule enhancement and ANN-based nodule detection algorithms are presented. The preliminary simulation result indicated the potential of this method for detection of lung nodules on chest radiographs.

I. INTRODUCTION

The cure of lung cancer is highly dependent on the early detection, while the tumor is still small and localized. Currently, the detecting rate for lung nodules (3 to 15 mm in diameter) is approximately 65%, and 30% of the missing nodules can be detected retrospectively.

Early detection of cancerous lung nodules in chest radiographs has been a clinically difficult and challenging task. Although skilled and experienced pulmonary radiologists can achieve a high degree of accuracy in the diagnosis of chest nodules, still the performance of using direct inspection is limited by the subjective decision criteria used by different radiologists, a time consuming detection cycle, and high miss rate of small and low contrast nodules surrounded by noisy anatomic lung background.

In recent research, digital image processing techniques have been widely used in developing computer-aided diagnosis (CADx) for pulmonary nodule detection. A group of researchers led by Dr. Kunio Doi have done substantial work in feature extraction and the analysis of lung nodule images.^{1,2} Their results showed a 70% true-positive detection rate with an average of three to four false-positives per chest image. Our optimal goal in this project is automatic lung nodule detection using ANNs which is expected to distinguish false nodules from true nodules.

Due to the sophistication and availability of traditional computer technology in radiology, the application of simulated neural networks in this field seems to be a promising alternative. Hardware-implemented neural networks also offer great promise. Conventional rule-based and algorithmic approaches often have failed in many radiology applications where the algorithms or the rules are not known a priori. Neural networks have several advantageous properties, such as fault tolerance, generalization, and the capability of learning from training data. The application of ANNs in diagnostic radiology has been enthusiastically received. One major issue here is how to turn the factors of clinical decision making into neural network readable information.

In addition to the implementation of digital processed algorithms for fast selection of suspected nodules and extraction of nodule features, we use a back-propagation ANN (BPANN) as a classifier, intended to distinguish between false nodules and true nodules. The program is fully automatic and simulation results are fairly encouraging.

II. MATERIALS AND METHODS

Our lung nodule detection scheme involves the following stages: (1) data acquisition, (2) signal enhancement, (3) selection of suspected lung nodules, and (4) ANN-based nodule classifier.

1. Acquisition of digital chest images

The digital chest images were obtained by digitizing radiographs with a Konica Laser Film Scanner (KDFR-S) and transmitted to a Micro-VAX II host computer. These images were formatted in $2048 \times 2500 \times 10$ bits of computer information where each image pixel represents 175μ square in a $14" \times 17"$ area. Since most radiographically detectable nodules are larger than 3mm in diameter (i.e., ≈ 18 pixels in 2048×2500 image), each pulmonary radiograph was subsequently shrunk to $512 \times 625 \times 12$ bits. Thirty digitized chest radiographs having nodules were randomly selected as our database.

2. Enhancement of lung nodule signal

Since some nodules are not easy to identify, a nodule enhancement procedure is conducted for each pulmonary radiograph. A difference image is obtained by subtracting a nodule suppressed image (a median filter with a kernel size of 1.5 cm was used) from a nodule enhanced image (i.e. a matched filter of sphere profile with 1.5 cm in diameter was used). Note that the matched filter used white noise as the background noise in the radiographic image. This nodule enhanced technique involves complex matrix multiplication, 2-D FFT, and background correction.³

3. Selection of suspected lung nodules

Once the nodule enhanced image is obtained from the nodule enhanced and nodule suppressed images, an area extraction technique is applied to isolate possible nodules. This process involves a contour searching technique and

circularity test.¹ It takes 25-30 seconds to search for suspected nodules on the nodule enhanced image.

We preset three different levels of circularity for various detection sensitivities: (a) low confidence (high sensitivity) - 0.8 to 0.85, (b) moderate confidence (moderate sensitivity) - 0.85 to 0.9, and (c) high confidence (low sensitivity) - 0.9 to 1.0. A brief set of computer execution steps is given below:

- (0) search a pixel value greater than the threshold value
- (1) trace the boundary of an area having pixel values greater than the threshold value
- (2) find the centroid of the area
- (3) compute circularity and effective diameter
- (4) compare circularity with pre-specified sensitivity level
- (5) mask the area with a value below the threshold value (e.g., 0)
- (6) go back Step 0 to continue

Through the nodule enhanced processes and the circularity test, all round and nearly round objects in the nodule enhanced image were selected. However, nodules, vessels, and sometimes rib crossing areas were identified as suspected areas. Rib crossings are easily identified. But some of the vessels are very difficult to distinguish them from true nodules even for an experienced chest radiologist. Therefore, it is not easy to find a perfect method for the lung nodule detection by using only a single radiographic information.

4. ANN-Based nodule classifier

We made our first attempt to use a neural network as a classifier to distinguish the rib crossings and round vessels from the true nodules. Preliminary results indicated neural networks to be promising as nodule classifiers.

4.1 Image block database for ANN

The database for training and testing ANN consists of all suspects of the nodule enhanced image blocks. The database was divided into three categories: (a) non-nodule, (b) nodule, and (c) calcified nodule cases. The radiologist were able to identify most of the nodules on the X-ray films with known diagnosis. We then run all the digitized chest images through the program with the highly sensitive mode to capture the suspected areas. The program captured all single nodule cases. However, three nodules with complicated backgrounds on multi-nodule films were not captured. These three nodules were manually selected and put into the database. All cases were confirmed by the radiologist. Some "non-nodules" from multi-nodule films were deleted from the non-nodule category. Because the objects were superimposed by other lung tissues, vessels or possible extensions of adjacent nodule structures make them very difficult to identify. In addition, we found many non-nodule areas were selected in this preliminary nodule search.

4.2 Neural network architecture

A feed-forward neural network was constructed as a two-layer structure (i.e., a single hidden layer neural network): (a) the input layer, which consists of 1024 nodes with each node accepting each pixel value on the image block (32×32

elements); (b) the hidden layer, which consists of 100 to 200 nodes in this experiment; and (c) the output layer, which has two or three nodes. The architecture of the two-layer feed-forward neural network is shown in Fig. 1.

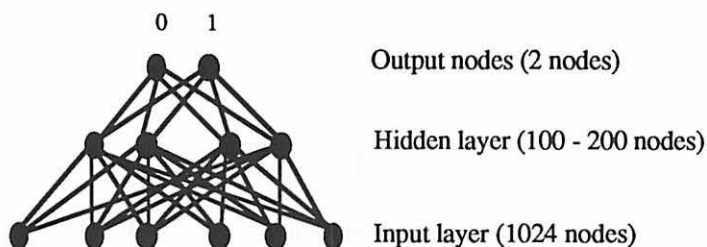


Fig. 1. A neural network structure as lung nodule classifier

On the output layer, node 0 is assigned to non-nodule cases and node 1 is assigned to nodule cases. Note that we used only two output nodes even though there are three categories of nodules in our database. Each of the gray values of the nodule enhanced image block (32×32) of the suspected area, which are determined by the preliminary search with high sensitivity, enters into each input node (total 1024 input nodes) of the neural network.

4.3 Learning of neural network

We used a back propagation learning rule (δ -rule)⁴ to adjust the weighting coefficients between different nodes. Two sets of weights, corresponding to (a) input and hidden layers and (b) hidden and output layers, were stored in the computer disk as two separated files which can be retrieved for further training and future tests. The learning rate can be modulated according to different network complexity. The sum of squared-errors were decreased throughout the learning phase. In this simulation, learning is terminated at a reasonable small sum squared-error (≈ 0.5).

4.4 Testing of neural network

Before testing an image block on the neural network, the weighting coefficients must be first resumed at the corresponding synapses. The input values were given as those for the training image block. In this study, the value at each output was normalized. Only nodes 0 and 1 were of concern. This is because the normalized output value at node 1, P_1 , is equivalent to the probability of the test image block containing a nodule. P_1 is given by:

$$P_1 = \frac{\left(\sum_k v_k \right) - v_0}{\sum_k v_k} \quad \dots(1)$$

where V_k is the original output value at node k .

To test a chest image, the image was first processed by the nodule enhancement process. The image block extraction was determined by the high sensitivity mode of the circularity test. The suspected image blocks were then fed into the trained neural network. Once the normalized output value at node 1 is greater than a preset threshold, the suspected nodule would be identified as a tumor. The scheme for lung nodule detection is shown in Fig. 2.

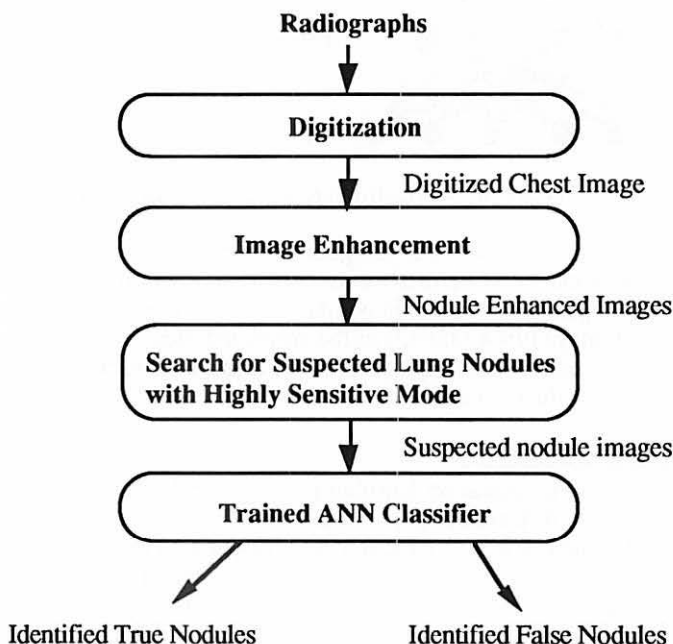


Fig. 2. Lung Nodule Detection Scheme

III. SIMULATION RESULTS

In our initial attempt to distinguish true nodules from false nodules, we used the two-layer feed-forward neural network which was trained by a generalized δ -rule. Several parameters were preset in the neural network training using the above network structure. The learning gain was set at 0.15. In the forward propagation, each node received a non-linear weighting contribution using a sigmoid function. The sum of squared-errors were converged starting from about 200 iterations and continuing up to 400 - 500 iterations for all training. Image blocks in the training set received 100% correct detection of nodule and non-nodule when the cut-off was set at 0.5 for the the normalized output value at node 1 (or the sum of nodes 0 and 1).

In the neural network experiment, two different training arrangements were tested. The values of P_1 resulting from the neural network test for each suspected image block from the test set were recorded and put into two categories: (a) non-

nodule and (b) nodule. The first category contains the P_1 values from the non-nodule blocks and the second category contains the P_1 values from the nodule blocks. Both categories were analyzed by evaluated using receiver operating characteristic (ROC) methods⁵ for evaluation to see how the neural network performs. In practice, the data were entered into the LABROC program made by Dr. C. Metz and his colleagues.⁵

In the strictly non-mixed experiments, one can also use a point on the ROC curve for evaluation such as a 70% TPF (true positive fraction) rate with a 50% FPF (false positive fraction) rate (i.e., about 2-3 false nodules per image). This result is comparable to those described previously in the literature [1,2]. Note that this initial result should not be considered as the real performance of the proposed neural network. More clinical testing should be done to prove the consistency of performance. However, the results indicate that neural networks have some potential to detect nodules.

Experiment 1:

Number of nodes on the hidden layer: 200

Number of output nodes: 2

Training set :

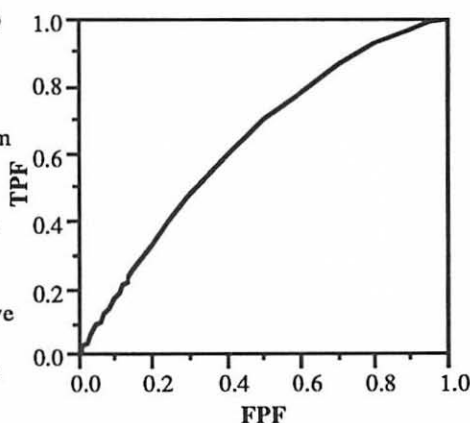
4 images consisting of 20 multiple nodules and 40 false nodules detected from the preliminary evaluation.

Test set:

26 images consisting of 39 true nodules and 135 false nodules.

Results:

The figure shown below is an ROC curve in which $A(z)$ is 0.634 with standard deviation (SD) 0.049 (where $A(z)$ denotes the area under the curve).



Experiment 2:

Number of nodes on the hidden layer: 200

Number of output nodes: 2

Training set :

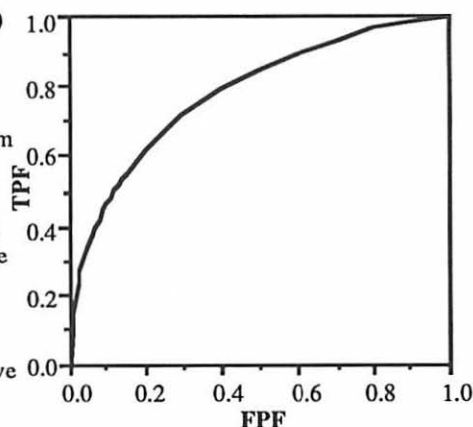
12 images consisting of 20 multiple nodules and 40 false nodules detected from the preliminary evaluation.

Test set:

22 images consisting of 36 true nodules and 117 false nodules. (Some images were used in both sets, however, cases are not mixed in both sets)

Results:

The figure shown below is an ROC curve in which $A(z)$ is 0.782 with SD = 0.044.



IV. CONCLUSIONS AND DISCUSSION

Experiment 1 shows that the results of using the neural network were as good as the circularity test methods. However, experiment 2 shows that the detection is greatly improved when a mixed-image set was used. This may result from two factors: (a) the correlation of both the training and the test image blocks on the same images and (b) the contrast information was randomized in experiment 2 and not clearly presented in experiment 1. We certainly hope that (b) is the main factor. We need to further test new images using these three trained neural networks to find which factor dominated the learning. In addition, only 4 images (20 nodules) were used for the training in experiment 1, too few to establish any firm conclusion. In addition to increasing the size of the database, several parameters could be improved, including: (a) control of the variety of image contrast on the original film, (b) elimination of the background noise, (c) more specific nodule features, (e.g., the slope or contrast of the suspected nodule), and (d) patient information (e.g., patient age, smoker or non-smoker, and patient diagnostic history).

Although the subtracted images show the enhancement of potential nodules, there is information loss in the process. For example, some nodule images, especially those overlapped with ribs and vessels, have been deformed after image subtraction and won't be detected by circularity test. The 32×32 images still contain background and texture patterns on the lung. These background noises may be helpful in training neural networks. If so, this implies that there is certain information regarding the nodule and background noise reside in the background corrected images. Some nodules are not "round" and would not pass the circularity test. These nodules sometimes can be observed by radiologist. By investigating the false-positive nodules, we found that some nodules (e.g., calcified nodules) could not be detected if we used an improper threshold value in the growth test. During the investigation of subtracted nodule images, we noticed that some nodule information is not detected with these parameters setting in highly sensitive parameters. This is due to the fact that many true nodules are not "round", especially those overlapped with ribs and vessels.

In a typical neural network training, the design of the network structure, a good set of the training samples, and sufficient repetition are essential. Incorrect training and teaching data might confuse neural networks which in turn degrade their capability as nodule classifiers. The sum of squared-error over iteration did not converge when we used background-corrected nodule images as training sets. We do not know why it did not converge, however, possible factors are the noisy lung background and the low contrast information of the nodule blocks on the original digitized films. The neural network converges for most cases if we use nodule enhanced images as training data. Detection of the training set has a rate close to 100% for various experiments. From this study we found that the neural network seems to work if a proper training set is given and that, therefore, the use of ANN to assist in detection of lung nodules is highly feasible. Other features, however, may be needed to further distinguish the nodule characteristics as indicated earlier.⁶ We also employed the moment invariant transformation of the nodule images to generate feature vectors (each containing seven moments). These

feature vectors are used as training and testing input of ANN. However, the results of this experiment were not encouraging.

ACKNOWLEDGEMENTS

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Computer Assisted Diagnosis (CAD) in Mammography

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1.0 INTRODUCTION

The application of computer assisted diagnosis (CAD) in digital mammography involves both *image enhancement techniques* and *pattern recognition methods* [1-4] with the objective of increasing the sensitivity and specificity of detecting breast cancer. The requirements for image enhancement techniques are the focus of this work which examines the ability of these methods to enhance the fine details of normal parenchymal tissue structures, suspicious tumor areas or microcalcification clusters [1-4], while optimally suppressing noise. Methods previously reported in the literature have included linear filtering techniques such as edge preserving smoothing, k nearest neighbor, directional smoothing [1-6] and more recently selective median filtering [1] that locally adapts to the image gray scale. However, in most instances conventional linear filtering or selective median filtering fails to preserve image detail while suppressing image noise. These methods therefore, generally introduce linear artifacts or structured noise that results in unacceptable high false positive detection rates for suspicious areas or microcalcification clusters [7].

This paper reports on preliminary results of a new class of non-linear filters that have more robust characteristics for noise suppression and detail preservation for mammographic screening namely: (a) a tree structured non-linear filter [8,9] and (b) a single non-linear filter with adaptive filter windows [9]; both filters are collected with a dispersion edge detector. These two filter types are evaluated using representative mammographic images with different tumor types and are also compared to the well known Sobel edge detector.

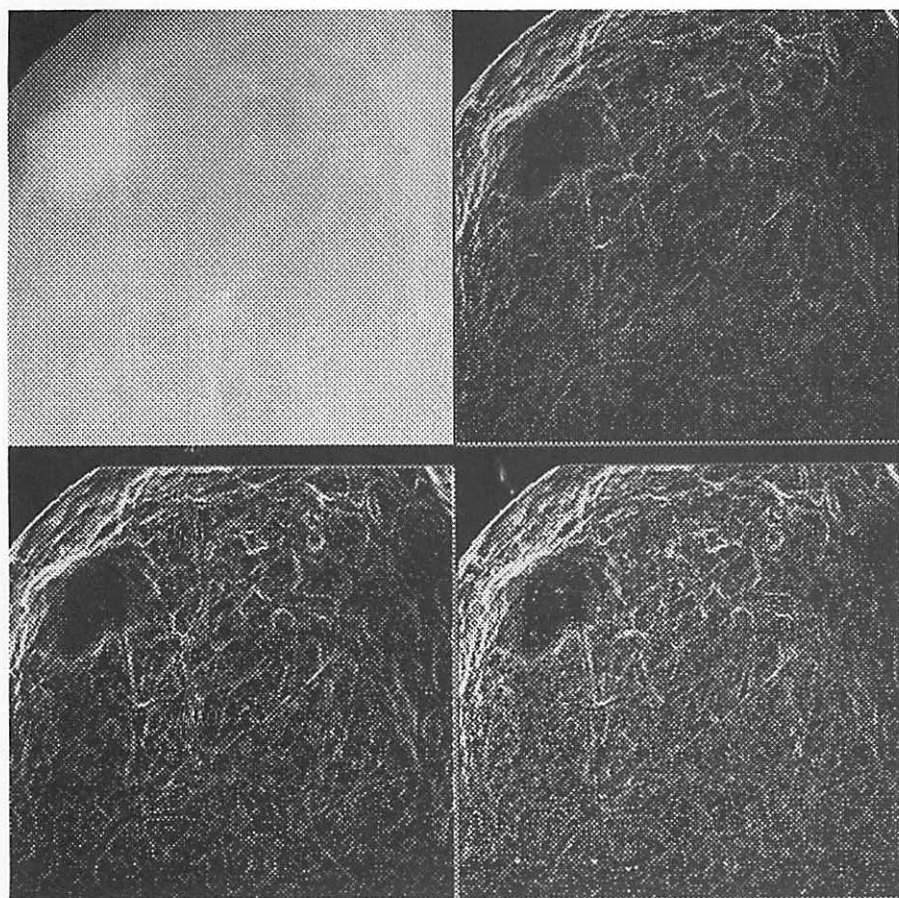


Figure 1: Representative mammographic images of a circumscribed tumor with irregular margins: (a) top left: raw data, (b) top right: tree structure filtered data, (c) lower left: single filter and (d) lower right: Sobel operator.

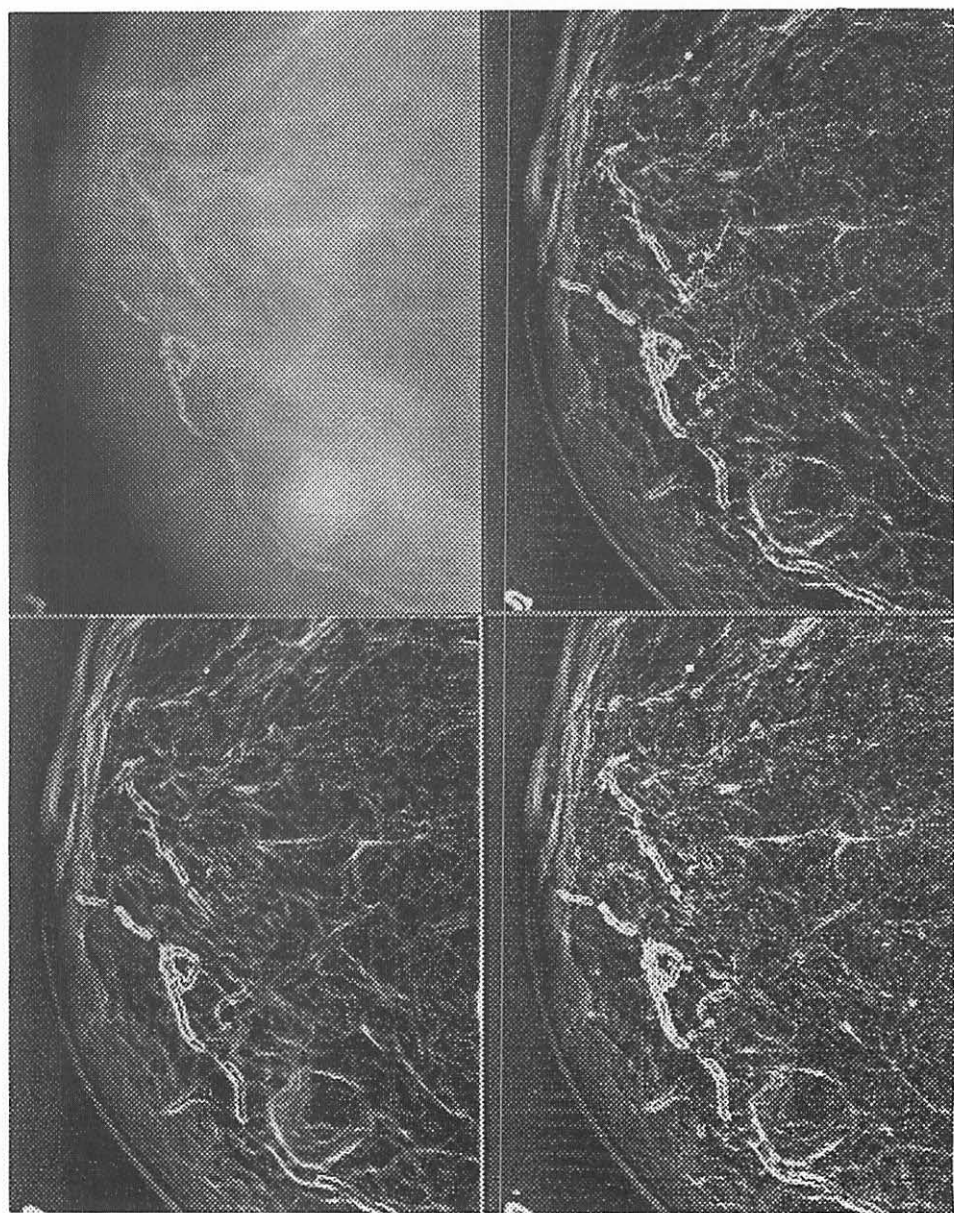


Figure 2: Representative mammographic images as per Figure 1 of a circumscribed tumor with smooth margins.

2.0 MATERIALS AND METHODS

2.1 Tree Structured Filter

The tree structured filter has three stages. The basic filter in the first stage is a central weighted median filter (CWMF) and central weighted median operations (CWMO) are used as conjunction nodes for stages 2 and 3. The weighted median filter is an extension of a median filter which gives more weight to some values in the filter window to preserve image details [6]. The CWMF and the CWMO proposed here, within the tree structure, is a special case of the weighted median filter which gives more weight to the central value of a window. The tree structure basic filter incorporates fixed linear and curved windows to further improve the multidirectional fine details of parenchymal tissues or fine structures of microcalcifications. The output of the tree structured filter is finally cascaded with a dispersion edge detector. This new class of tree structured filter is described in detail elsewhere [8,9].

2.2 Single Filter with Adaptive Windows

A single non-linear filter is also proposed cascaded with the same dispersion edge detector. The performance of the filter is improved by introducing adaptive techniques for the selection of various curved windows, which have potentially more desirable properties for both noise suppression and curve detail preservation. We are currently evaluating several adaptive techniques for the selection of the appropriate window for each pixel and these results will be published elsewhere [10].

3.0 RESULTS

Representative results are shown for three types of breast tumors as indicated in Figures 1-3. In each instance images for: (a) (top left) raw data, (b) (top right) tree structured filter, (c) (lower left) single adaptive window filter and (d) (lower right) Sobel operator, are shown for each tumor type. The raw data images were originally obtained using X-ray film and digitized using a laser transmission device; matrix size of 1K x 1K, 210 μm /pixel resolution and 8 bits deep.

The tree structure non-linear filter and the single non-linear filter with adaptive windows demonstrated better noise suppression and detail preservation than the Sobel operator for all three representative mammographic images. The tree structured filter in turn demonstrated slightly better image enhancement of very fine parenchymal detail compared to the single filter. Alternatively, the single filter with the adaptive windows demonstrated better preservation of larger parenchymal tissue structures in particular the curved detail compared to the tree structured filter. Both filters demonstrated comparable noise suppression.

4.0 CONCLUSION

The objective of the proposed image enhancement and edge detection methods is the pre-processing of image data for pattern recognition methods for tumor or microcalcification detection or identification of normal mammograms. Ideally these image enhancement and pattern recognition methods should be unsupervised or automatic and efficiently executed on medically expert workstations.

The tree structured filter with appropriate optimization of parameters may potentially be very suitable for the detection of microcalcification clusters, or tumor areas [9]. The single filter with adaptive windows may be better suited for identification of the curved detail of parenchymal tissue as required for measurement of breast density and classification of parenchymal patterns [8-11]. Alternative techniques are also being explored such as the use of modified hierarchical neural networks or wavelet transform for tumor or microcalcification detection. These advanced image processing methods are being directed at the development of a fully automatic method for mammographic cancer screening.

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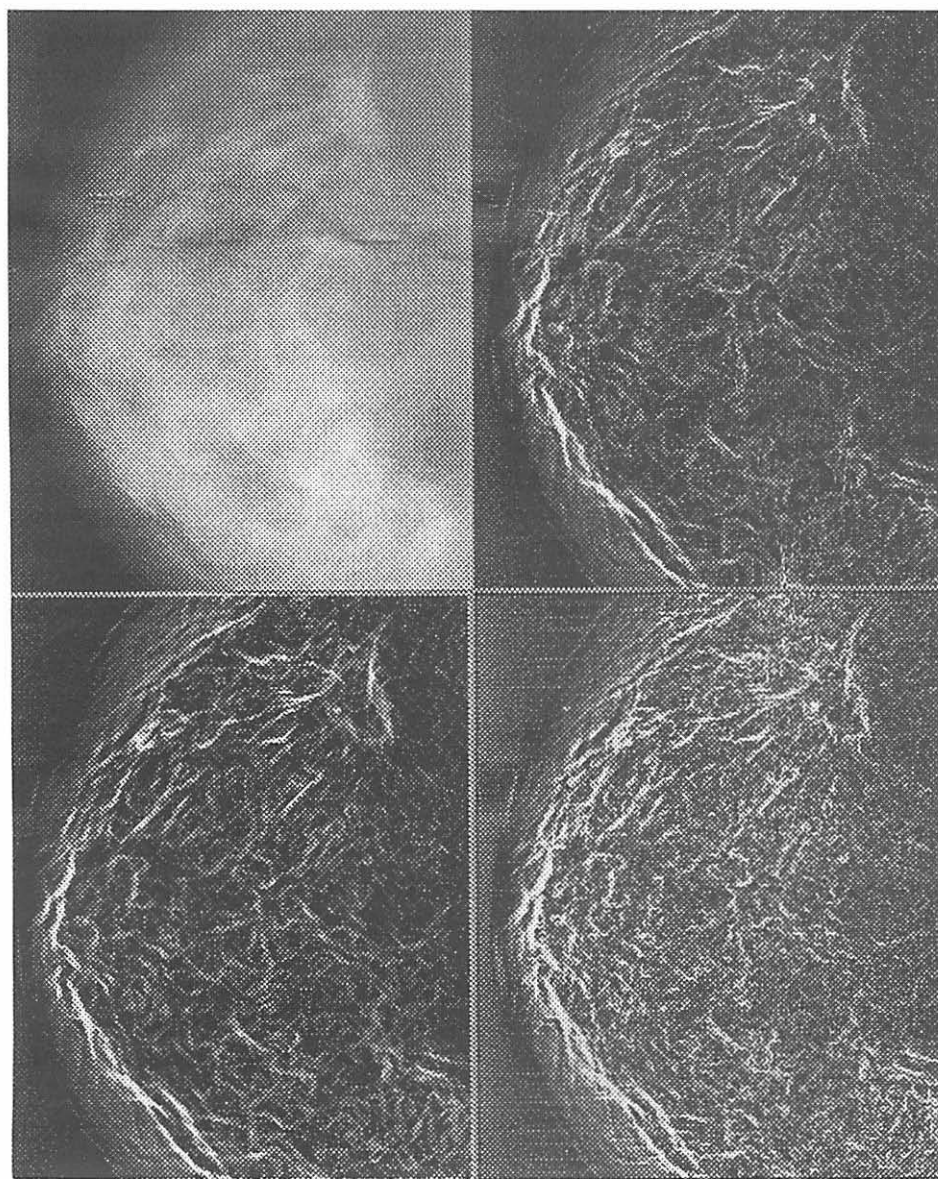


Figure 3: Representative mammographic images as per Figure 1 of a speculated tumor mass.

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Digital Flashing Tomosynthesis: A Promising Technique for Angiocardigraphic Screening

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I. INTRODUCTION

Digital angiocardiology is widely accepted as a useful clinical and investigative tool for the quantitative assessment of obstructive coronary artery disease (CAD) and regional left ventricular function. One of the most important questions now facing the cardiovascular community is, whether it is possible to assess an early stage of CAD and to demonstrate significant progression or regression resulting from therapeutic interventions. Computer-assisted quantitative assessment is an accepted method to study the efficacy of such interventions. However even this technique has inherent limitations and difficulties related to the interpretation of the angiographic information. These problems may be solved by new, individual patient-defined, standardized and reproducible configuration of digital angiocardiology as a fundamental prerequisite for angiocardigraphic screening.

In addition, it has long been the angiographer's desire to depict the anatomy and morphology of coronary arteries in three-dimensional (3D) presentation. Moreover, today's and future interventional cardiology demands a valid concept for the quantitative assessment of both progression of disease and regression of coronary lesions with optimal reproducibility using 3D reconstruction from multiple projections. However, the mathematical problem of 3D reconstruction from only two projections is that of a highly insufficient set of data matrix.

For the coronary artery tree an entirely new approach is required, since conventional and computed tomography are not suitable for imaging the rapidly moving coronary arteries due to the long acquisition time. Flashing tomosynthesis is an innovative concept to avoid these limitations [1]-[3]; a configuration with 24 or 16 X-ray tubes has been tested for visualization of the coronary arteries [4]-[6]. Digital Flashing Tomosynthesis (DFTS) represents the latest development of the digital tomographic technique [7] and may even allow angiocardigraphic screening with 3D presentation of coronary lesions, including complete quantitative analysis and individual digital archiving for each patient.

II. DFTS - SYSTEM

Recording equipment. The recording equipment of a DFTS system consists of 4 ECG-gated X-ray tubes with a rotating anode (Philips SRO 20-55) simultaneously

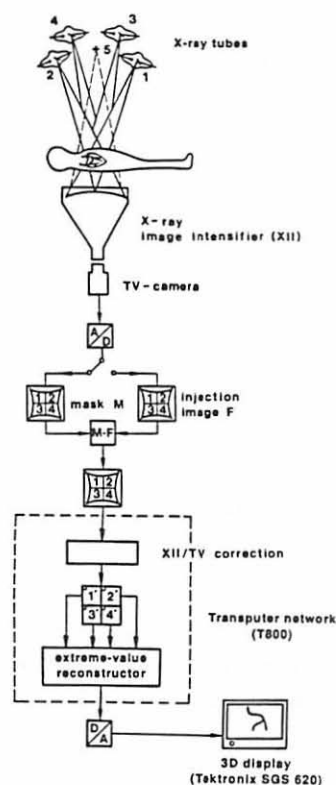


Fig. 1 Principle of DFTS

Image acquisition. The radiation exposure time of flashing tomosynthesis is less than 40ms, but varies with the body mass of a given patient. Each ECG-gated X-ray flash generates a multiperspective image, i.e. the DFTS-multiangiogram. For dynamic studies a series of ECG-synchronized DFTS-multiangiograms may be generated in any selected phase of the cardiac cycle. Each generated DFTS-multiangiogram can be used for the reconstruction of DFTS-tomoangiograms either as a single slice or as multiple slices of arbitrary thickness [7]. For digital subtraction angiography (DSA) an ECG-synchronized DFTS-multiangiogram or a series of DFTS-multiangiograms of the coronary arteries without contrast media can be flashed and used as a mask.

Distortion correction. The real-time digital distortion correction unit [8] consists of an input memory for storing the distorted image, an output memory for storing the corrected image and a special address memory during the correction process. The correction of images is performed by an assembler program on the 32-bit 680X0 microprocessor system requiring no arithmetic operations during the correction process and reducing the execution time to 100-300 milliseconds per 512x512 8-bit image. With this approach the distortion correction technique is applicable to any real-time analysis in digital quantitative angiocardiology requiring precise spatial information such as

flashed by a 120 kW generator (Philips MCM 120) as shown in Fig. 1. All tubes are simultaneously powered by a voltage of up to 100 keV to deliver a current of up to 300 mA per tube. A detector consists of a conventional 14-inch X-ray image intensifier (Philips 14" XII) and TV system (2" Plumbicon XTV-6). This system is directly connected to a digital subtraction angiography (DSA) unit (Philips DVI-II) for direct digitalization. The system has a resolution of 512x512 pixels and 8 bits of grey levels. The X-ray tubes are arranged in the corners of a square array. The geometry of the DFTS system is characterized by a focus-object distance of 1050 mm, an object-image intensifier distance of 150 mm, and a field of view of 80x80 mm². The angle between the central beam of each pair of X-ray tubes is 58° providing a 30° RAO and 30° LAO view. In addition, each X-ray tube allows for a 45° cranio-caudal or caudo-cranial angulation. The array must be rotated to generate steeper cranio-caudal projections. The 5th X-ray tube is primarily used for positioning the patient under the DFTS unit and for placing the catheters under direct fluoroscopic control. Each X-ray tube can also be selectively used for imaging if required. Scatter radiation is reduced by an anti-scatter grid; the lamellae are adjusted according to the orientation of the corresponding X-ray tubes [5].

the quantification of left ventricular ejection fraction or stenotic lesions [7].

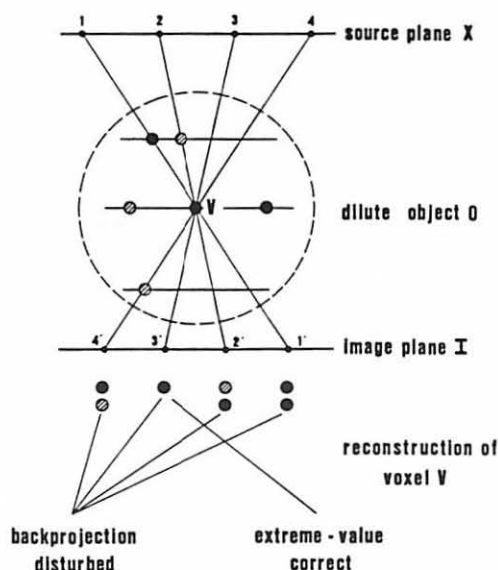


Fig. 2 Extreme-value reconstruction algorithm

3D reconstruction method. The extreme-value reconstruction algorithm [9] for nonlinear decoding is illustrated in a simple model as shown in Fig. 2. The highly absorbing voxel V (black point) of the diluted object O is projected from 1-4 X-ray tubes in the source plane X into the assigned pixels in the image plane I. The projections 2' and 4' of voxel V from the X-ray tubes 2 and 4 are overlapped by the projections of one or two voxels in other planes with relatively small absorption (streaky points). The projection 1' from X-ray tube 1 is covered by a voxel with high absorption (black point), whereas the projection 3' from X-ray tube 3 is devoid of any overlapping. The reconstruction of voxel V by extreme-value decoding yields the pixel with the smallest grey level.

In this example pixel 3' represents the exact value of the voxel V. When almost all voxel values are near zero and only few voxels have distinctly greater values, the extreme-value decoding process provides excellent reconstruction, since the projections are determined mainly by the few highly absorbing voxels. This principle holds true in digital angiocardiology after cancelling out bone and soft-tissue by subtraction techniques. A necessary condition for an exact reconstruction of a voxel by the extreme-value decoding process is the free projection from at least one source. With an earlier version of flashing tomosynthesis it has been shown that this reconstruction method yields images of diagnostic quality by the use of only four projections [6]. However, artifacts are still present, but they can be easily recognized using a rotating 3D image presentation [7].

The pixel-oriented extreme-value algorithm is well suited for a parallel implementation on a PC-hosted transputer network (T-800) as shown in Fig. 3. First, for (parallel slice) reconstruction the minimum value is chosen between projections A and B (node 1 and 2) and simultaneously between projection C and D (node 3 and 4). In a second step the resulting signals are compared in node 0 for final determination of the minimum value. Nodes 0 and 5 are used to compute new projections using the maximum-intensity-projection algorithm (MIP) [10]. The computing time of a new projection (256x256-matrix) amounts to 15 seconds which is tolerable for clinical use. The degree of parallelization can be further improved by partitioning the projections into sub-images for even faster reconstruction [10].

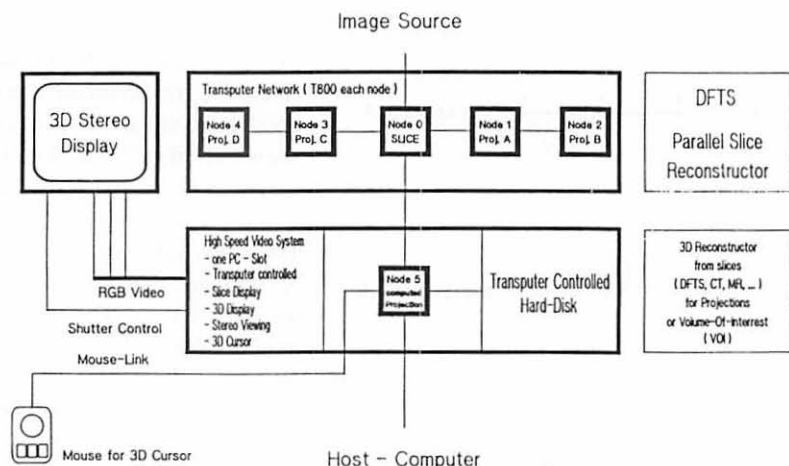


Fig. 3 PC-hosted transputer network for 3D reconstruction

Quantitative coronary angiography. An array of digital measuring functions is available for quantitative coronary angiography such as manually controlled stenosis measurement (caliper method) or automatic stenosis measurement with automated detection of both the vascular edges and the centerline of the vessel. In addition, an interactive contour correction, diameter statistics as well as densitometric and hemodynamic analysis and the calculation of plaque mass are available.

Quantitative ventriculography. Manual and automatic determination of ejection fraction are available for quantitative analysis of left ventricular function. Analysis of wall motion is feasible by applying either the regional, centerline or Slager method.

Image archiving. A complete digital examination with DFTS including source and reconstructed images as well as processed images with results of a quantitative analysis and procedural data or, alternatively, the fully processed digital images can be archived on high resolution S-VHS video tapes for reanalysis of data or for duplication. A separate archiving medium is installed for each patient. In addition, quantitative data on ventricular function and stenosis geometry may be recorded on a hard copy imager such as a laser imager to fulfill legal requirements.

Stereographic presentation of 3D data on a Tektronix SGS 620 monitor combined with a liquid crystal shutter plate is available.

Rotating presentation of 3D data. DFTS has the potential to obtain reconstructed 3D images of the coronary artery tree. Each coronary artery can be displayed in a rotating fashion about an arbitrary axis mimicking the 3rd dimension. An example of 20 synthetic projections spaced at intervals of 3° is given in Fig. 4. A continuous virtual rotation of the coronary artery tree is performed by displaying these images sequentially on a monitor screen. The 3D reconstruction of the ECG-synchronized dynamic tomoangiogram may also be presented and studied in similar fashion.

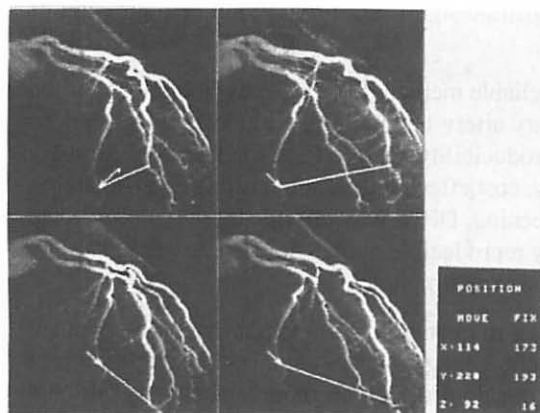
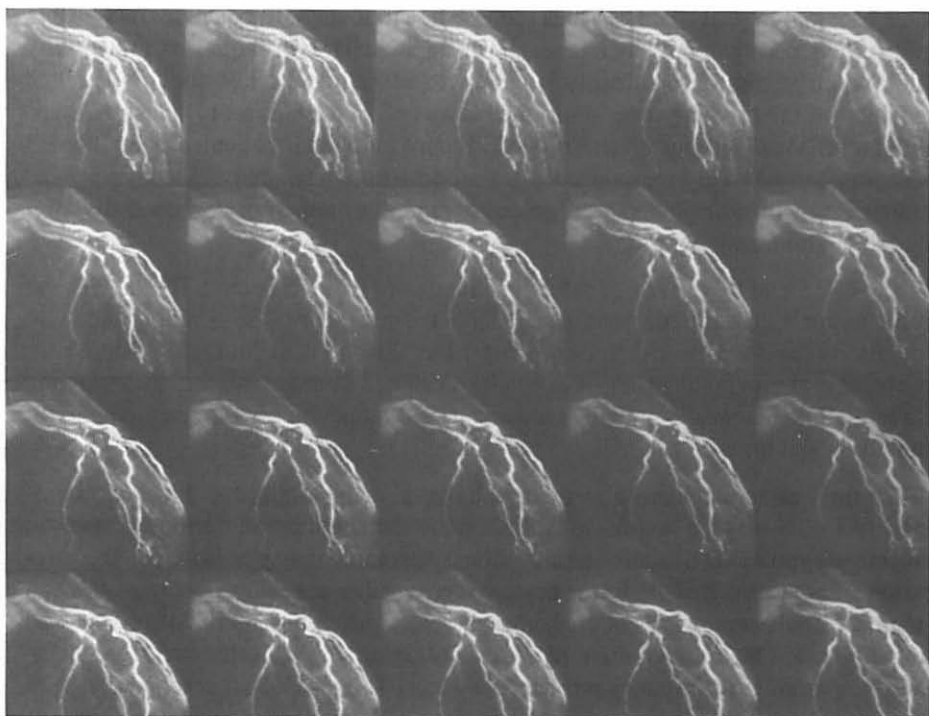


Fig. 4 DFTS-multiangiogram of left coronary artery (upper panel) and 20 computed projections spaced at intervals of 3° used for continuous rotation by displaying these images sequentially on a monitor (lower panel). Multiple-stereosynthesis: distance measurement inside the arterial tree in the 3D space (upper panel).



III. CONCLUSION

The longitudinal assessment of the coronary pathology, i.e. of coronary atherosclerotic lesions is a prerequisite for the exact and quantitative assessment of therapeutic interventions in modern cardiology. Not only interventions such as various forms of angioplasty, but also dietary and cholesterol lowering drug-intervention trials have resulted in less progression or even regression in selected patients [12]-[15]. However, to consolidate these encouraging results of new pharmacological intervention trials a high volume of patients in large scale trials has to be screened and followed up regu-

larly by angiography in order to demonstrate significant progression or regression of coronary lesions.

Thus, there is an urgent need for a reliable method, first, to assess the impact of the process of atherogenesis on the coronary artery lumen and on blood flow, second, to provide the image resolution and reproducibility required for quantitative coronary angiography and, third, to ensure safety, cost effectiveness and feasibility on an ambulatory basis for angiocardigraphic screening. DFTS may provide these features in the near future, merging a rapid and highly reproducible outpatient coronary angiography setting with all prerequisites of quantitative angiography.

The potential sources of error related to quantitative angiography can be avoided with DFTS. Once the magnification, tube-voltage and frame exposure are optimized and set for best contrast and minimal quantum noise and motion blur, no additional patient-related and procedure-related sources of errors (or variability) have to be controlled. Methodological characteristics such as the motionless, fixed angiography table imply further conceptional advantages of DFTS in ensuring optimal reproducibility for follow-up studies and markedly lower costs. More importantly, the tomographic acquisition of the coronary tree in multiple layers of voxels allows to select the optimal angle of view for any given lesion of an any individual patient. Once recorded this setting can be easily reproduced in any follow-up DFTS study. The routines for quantitative evaluation of stenoses (geometric and densitometric) can be easily applied to DFTS-tomoangiograms.

Since DFTS can be performed safely in ambulatory patients using 5 F catheters and relatively small amounts of contrast medium the prospect of screening patients at moderate or intermediate risk for coronary heart disease is encouraging. Moreover, nonselective angiography using a specially designed catheter placed in ascending aorta will allow diagnostic imaging with significant reduction of contrast medium, radiation dose and time.

Therefore, as an ambulatory method with digital data storage and excellent reproducibility DFTS may be helpful to address more demanding and currently unsolved problems. Regular DFTS studies of the coronary anatomy may elucidate whether progression of atherosclerosis is linear or episodic, whether accelerated progression can be tampered by interventions and whether there are different patterns of progression or regression of CAD. In addition, the effects of aging may be separated from atherogenesis or from compensatory mechanisms [15]. Thus, DFTS in combination with quantitative analysis will be useful to elucidate both the pathologic mechanism of coronary atherosclerotic progression or regression and the efficacy of various therapeutic interventions.

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MRI: Medical Expert Workstation Using AI Techniques

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I. INTRODUCTION

MRI systems through discrete timing variations of RF and magnetic field gradients, measure spatial distribution of several parameters such as tissue relaxation and proton density related factors. The MRI data sets from the same anatomical slice or volume are analogous to the NASA Landsat images and referred to as multispectral (MS) data sets. The relative pixel intensities in the MS image data sets for each tissue class result in the formation of related tissue clusters in feature space, where the larger the number (N) of the MS image data sets results in higher order (N) feature space and hence should improve image segmentation [1,2,3]. Pattern recognition methods can then be used to resolve image intensity distribution into essentially a probability map of tissue types that potentially provide a greater confidence level image interpretation than simplistic gray scale approaches as applied to single MR images [1,2]. MS image segmentation has therefore been proposed for: (a) enhancement of tumor and edema boundaries or other tissues where MR relaxation parameters are fairly similar [3], (b) intelligent image fusion of MS 2D or 3D data sets, (c) improved target volume definition for 3D RTP and finally (d) electronic surgery simulation.

Contrary to calculated MR parameter based methods used for characterization of tumor type [4], image intensity based methods for image segmentation are not restricted to any physically defined MR parameters or tailored RF pulse sequences [1-3,5]. For example, RF sequences that are not MR parameter based may be used such as k space trajectory techniques, rapid acquisition with relaxation enhancement or fast magnetization preparation techniques. The stability of segmentation methods therefore on the selection of the particular RF pulse sequence is important to evaluate. Similarly, since these specialized sequences are instrument dependent, related stability issues are worthy of further study.

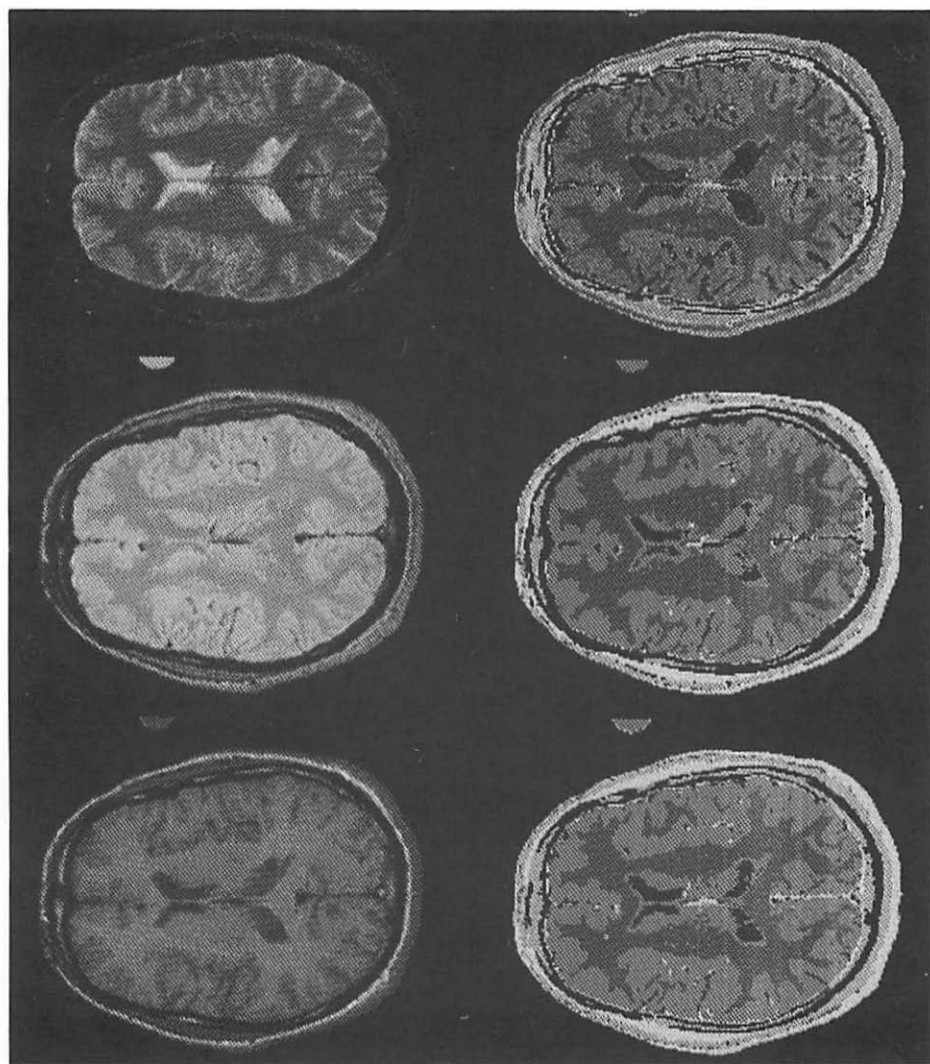


Figure 1: Segmentations obtained for SE sequences on General Electric MRI system

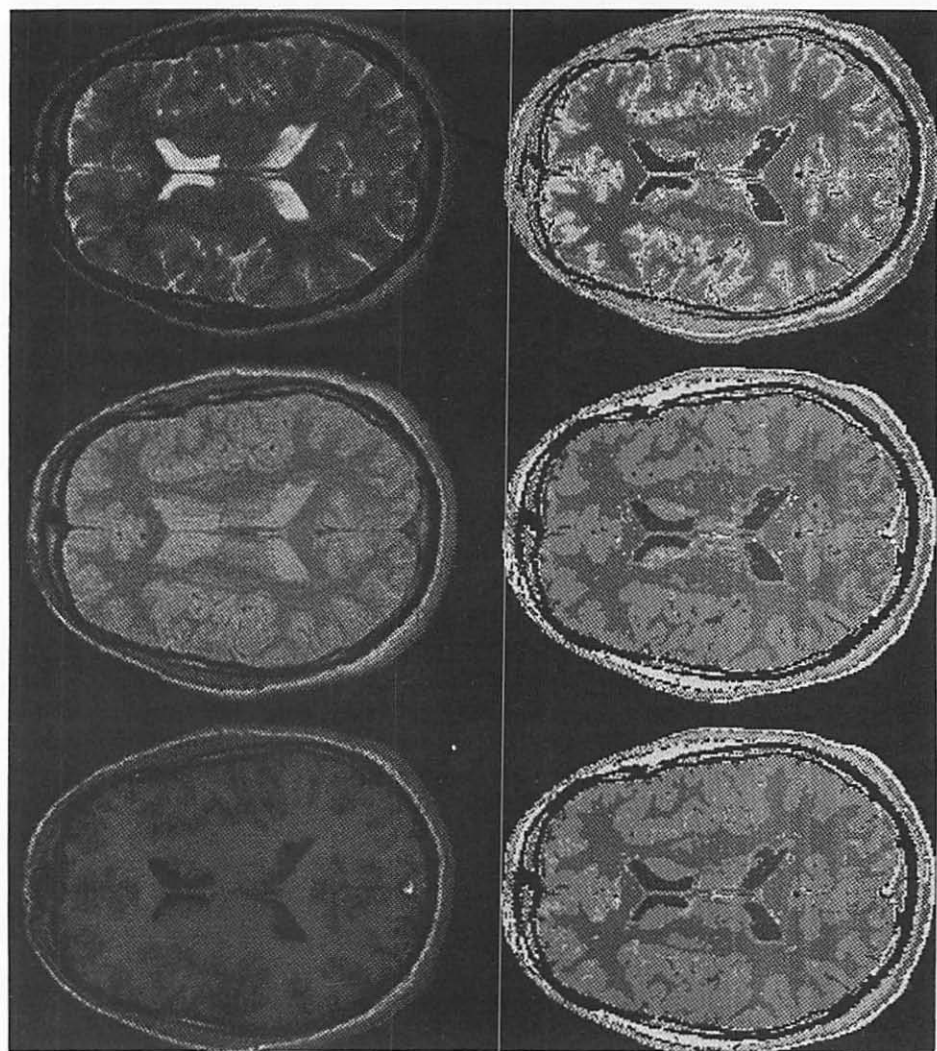


Figure 2: Segmentations obtained for SPGR and FAST SE on General Electric system

We have already investigated the stability of segmentation methods using conventional SE sequences using both supervised and unsupervised segmentation methods [1-3,6]. This report is a very preliminary evaluation of the stability of segmentation on RF pulse sequences and instrumentation factors using both supervised and unsupervised methods [1-3,6].

II. MATERIALS AND METHODS

2.1 Segmentation Methods. These included supervised methods such as k nearest neighbors (kNN) and feed forward cascade correlation (FFCC) (artificial neural network (ANN) with dynamic architecture) both of which require training data sets as previously reported elsewhere [6]. The training data sets (regions of interest (ROI)) were selected iteratively in the spatial domain (MS data sets) or in feature space to minimize the instability of segmentation on the location of the ROI's. The unsupervised segmentation method used was a fuzzy clustering approach or fuzzy c-means (FCM) that does not require training regions but only the anticipated number of tissue clusters. Details of this method are reported in detail elsewhere by these investigators [2,3].

2.2 Imaging Protocol. The MS image data sets on volunteers were obtained using the multi-element head coil of a General Electric Signa I and Siemens Magnetome 1.5 Tesla System. Images were obtained in the transverse plane of the head coil to minimize the necessity of RF field corrections required for image segmentation [7]. The influence of RF pulse sequence on segmentation was evaluated by acquiring SE sequences (TR = 600ms, TE = 20ms, TR = 3000ms, TE = 20, 80ms, 5mm slice) and a SPGR T_1 weighted sequence and FAST SE sequences (TR 4000ms, effective TE=16, 96 ms, 5mm slice); interleaved with 100% interslice gap on the General Electric MRI system. The influence of inter-instrument factors was measured using the SE sequence on both the General Electric and Siemens MRI systems.

III. RESULTS

Representative results for the influence of the RF pulse sequences on the stability of each segmentation method using the General Electric MRI system are shown in Figure 1 and 2. In Figure 1, representative raw MRI data are shown in the top row (left to right: SE T_1 , PD and T_2 weighted images) and the results of each segmentation method are shown in the bottom row (left to right: kNN, FFCC and FCM). In Figure 2 the raw MRI data is shown in the top row (left to right: SPGR T_1 , FSE



Figure 3: Segmentations obtained for SE sequences on Siemen's MRI system.

TE=16ms, FSE TE=96ms), the segmented images are shown in same order as Figure 1. The kNN method showed the best stability of segmentation as can be observed by comparison of the segmented images for each pulse sequence and method. The FFCC and the unsupervised FCM were slightly more unstable; the FFCC using the same training regions as the kNN technique, the selection criteria (ROI's), in turn, however, influenced the segmentation as previously reported [6]. The SPGR T_1 weighted sequence was found to introduce the major component of the instability; when it was replaced with a SE T_1 weighted sequence, all segmentation methods very stable.

The segmentations obtained for the Siemens MRI system for the same volunteer images displayed in Figure 1 are shown in Figure 3. The kNN method was again found to be the most stable, the FCM the most unstable. The Siemens images demonstrated better T_1 contrast than the General Electric system and the segmentation by the kNN method was better differentiated for these tissues. The unsupervised FCM segmentation method was unstable. However, the instability was partly due to the RF field non-uniformity effects of the Siemens head coil and the initializations of the FCM procedure that leads to convergence to a local minimum. These effects can be potentially avoided by using partially supervised FCM methods [8] and RF uniformity corrections [7].

IV. CONCLUSION

The universal clinical application of multispectral image segmentation ideally requires that the stability of segmentation to be relatively independent of the MR instrument employed. The image contrast and signal noise characteristics of MR images and related image artifacts are also instrument dependent and pulse sequence dependent. Similarly, differences in RF inhomogeneity or main field inhomogeneity with each manufactured MRI system are anticipated [7]. Although the kNN method proved to be the most stable in this preliminary report, we are investigating the use of partially supervised FCM methods for segmentation that may prove to be more stable [8]. The methods are being applied to a larger volunteer and patient data base to validate the results.

ACKNOWLEDGEMENTS:

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Automated Detection of Microcalcification Clusters in Mammograms

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Introduction

Breast cancer is the leading type of cancer incidence in women, causing about 170,000 new cases a year. Early diagnosis and treatment of breast cancer provide one of the highest chances of survival among cancer types in women [1]. A yearly mammogram examination for asymptomatic women over the age of 35 is recommended by the American Cancer Society; Medicare has recently agreed to cover these procedures. The number of women above the age of 50 in the U.S. exceeds 36 million and is expected to increase in coming years. Because awareness of breast cancer is increasing in the general public, it is possible that mammography will soon be one of the highest volume X-ray procedures regularly used in radiology clinics.. Automated methods that contribute both speed and accuracy to mammogram interpretation could help assist the radiologist and reduce their burden.

A key indicator of early cancer in mammographic interpretation is a cluster of microcalcifications; it is the first and sometimes the only sign in early, curable breast cancer [2]. The subtlety of some microcalcifications makes visual interpretation of mammograms a tedious and error-prone process, often requiring a lengthy inspection using a magnifying glass. In visual inspection, the probability of false negatives is high [3]. This low sensitivity is accompanied by a significant level of false positives: only one out of five cases that radiologists interpret as potential cancer is confirmed in a biopsy examination [4].

Background

Microcalcifications usually have a higher X-ray opacity than normal breast tissue and appear as bright structures ranging from 0.1mm to 2mm in width in the mammogram. Several factors make visual recognition of microcalcifications difficult: i) their small size and the relatively low contrast of mammography make recognition very subtle and tedious, ii) their variable size and morphology, and iii) mammographic microstructures

that are unrelated to cancer may have a size and appearance similar to those of microcalcifications.

Visual discrimination is often limited by the small size of microcalcifications, and in many cases the radiologist must use a magnifying glass to ensure that all microcalcifications can be seen. Lens-camera and scanner systems are able to achieve digitization resolutions (e.g. 25 microns/pixel) that provide adequate information on the smallest microcalcifications. The relatively low contrast of mammography can limit the performance of automated algorithms and human interpreters.

The central difficulty that must be overcome by a recognition algorithm arises due to the similarity of microcalcifications to other variable microstructures in the mammogram. Microstructures unrelated to cancer that can appear on mammograms include film artifacts, lead shot positioning markers, and benign tissue structures. Proximity of microcalcifications (clustering) is an important visual cue; a microcalcification cluster is defined as an area of about 1 cm^2 containing 3 or more individual microcalcifications.

Previous automated detection techniques [3, 5-7] gave varying levels of performance. The approach in [3], [5], and [6], based on a heuristic signal enhancement filter and local threshold crossing detection, was able to detect 90% of the microcalcification clusters along with several false positive clusters per mammogram. As stated in the conclusion of [6], i) the detection accuracy was lower than that of an average radiologist, and ii) it was intended to assist the radiologist by pointing out potential clusters and relied on the radiologist to rule out the large number of false positives. Better results were reported in [7] and [8]. The potential difficulties and pitfalls of available algorithms can be summarized as follows:

- 1) Too little enhancement can preclude the detection of minor microcalcification peaks while too much enhancement may produce a large number of false detections. An acceptable compromise may not exist in some images, and in those images where it exists, it can change from image to image and can be difficult to determine.
- 2) A small, square region of analysis (moving kernel) where operational parameters are computed, may not be appropriate for the variable shape of microcalcifications and automated detection based on such approaches may depart considerably, in some cases, from the outcome of visual detection.
- 3) A large number of parameters whose values have to be entered manually (e.g. [11]) is not a viable approach for expedient clinical use and does not provide the required level of objectivity.

These considerations and the unsatisfactory results that we obtained with some of the available algorithms on our clinical data led us to develop a fundamentally different detection algorithm designed specifically to address these shortcomings.

Methods

Data acquisition

Four mammograms, in each of which a single microcalcification cluster had been identified during the visual inspection of an experienced radiologist, were used in this preliminary study. Mammograms were uniformly illuminated and digitized in overlapping segments of 19.2 mm width by 12.8 mm height. Illumination of each mammogram was adjusted to prevent saturation. Segments were overlapped to prevent microcalcifications from appearing on segment boundaries. Each segment was imaged onto a Sony XC-77ce CCD array camera at a spatial resolution of 25 μm per pixel. Digitization at this resolution consists of oversampling of the image data relative to the modulation contrast function of the radiographic process, but could prove useful in discriminating post-radiographic artifact (e.g., emulsion pickoff) from small features in the recorded image. The 8-bit grey scale data from each segment was stored on magnetic media for subsequent numerical analysis and visual inspection. Portions of 2 of the 4 digitized mammogram used in this study and each containing a microcalcification cluster (circled) are shown in Figures 1 and 2. Each shows typical mammographic background structure, microcalcification clusters, and artifacts (including clinical markings) commonly encountered in clinical practice.

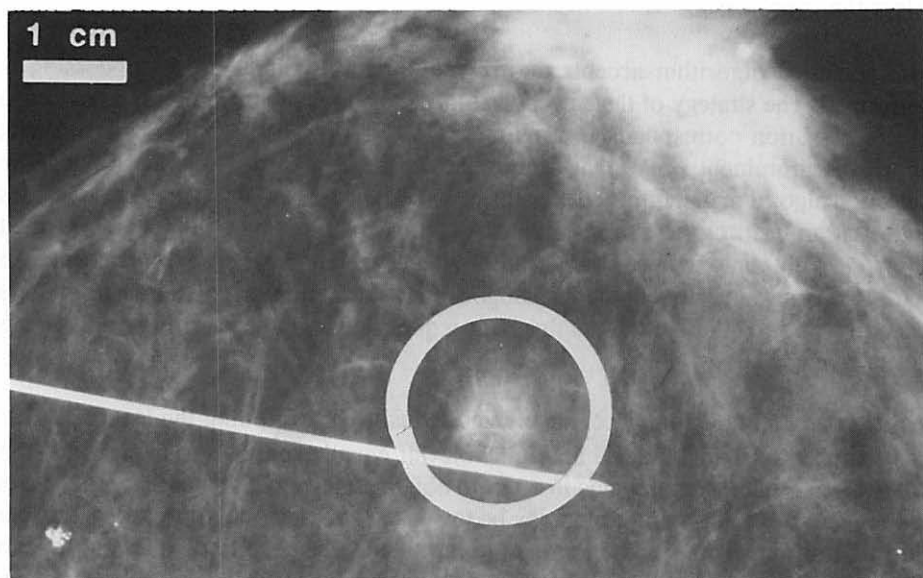


Figure 1

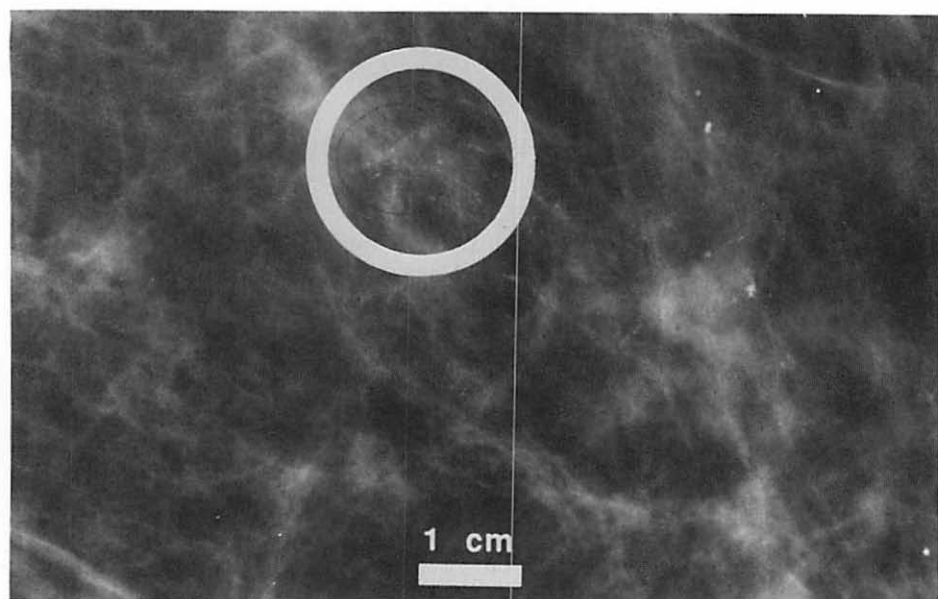


Figure 2

Algorithmic processing

The detection algorithm accepts digitized raw data as input; no preprocessing is performed. The strategy of the detection algorithm is to view the image as a landscape where elevation corresponds to brightness. In this perspective microcalcifications appear as prominent peaks that stand out with respect to the local surround. The detection algorithm determines the largest, smallest, and mean pixel (grey scale) values (u , b , and m , respectively) of the image. A contour plot of the entire image is formed (Fig. 3), with contour range based on the values u , b and m . The contours that we refer to are iso-intensity contours analogous to iso-elevation contours in cartography. Determination of these contours does not require local gradient estimates or edge detection calculations.

Pixels constituting a contour c_j have values equal to or exceeding the level t_j of that contour. Contours are obtained at different levels equally spaced by an amount e . The value of e is set to a small value in order to obtain an informative contour plot. If e is too high, e.g. 10, the contour plot may be too coarse. Setting e to 1 provides complete information but in most images is not warranted. The results of this study were obtained with e set to 5. Another possible approach is to set e adaptively for each image, in proportion to the range of the contour levels ($t_u - t_b$).

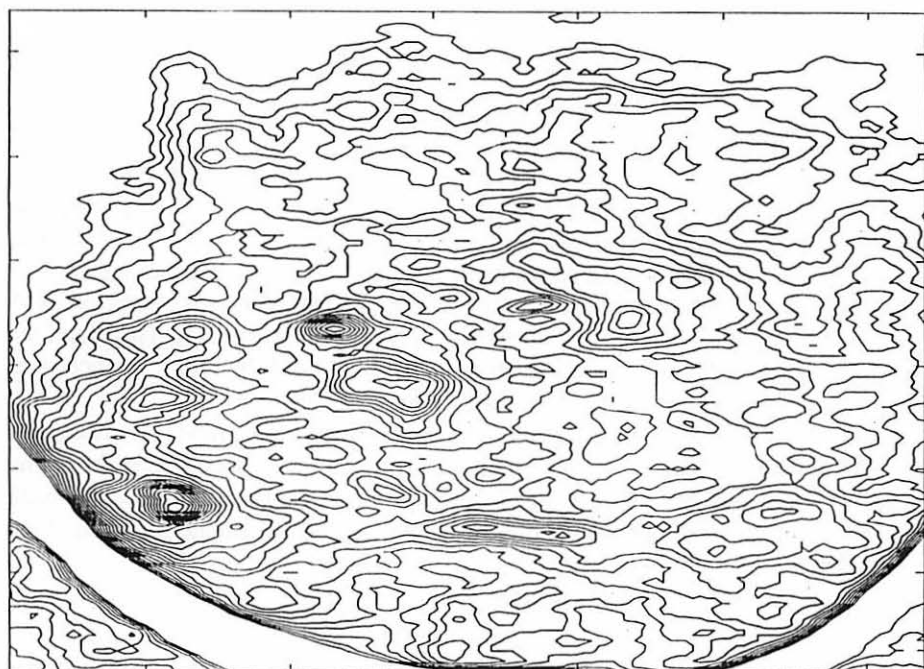


Figure 3

The largest value of t_j (t_u) is set to u-e. For a complete contour plot, the lowest level of t_j (t_b) has to be set to b. However, since microcalcifications typically are bright structures, t_b does not have to be set to b; setting it to a higher value saves computations without loss of information. The results of this study were obtained by setting t_b to m.

Once the contours at all selected levels have been obtained, the detection algorithm focuses on concentric contours. Each set of concentric contours that represent a peak (an individual microstructure) is analyzed separately. The algorithm obtains a sequence of contour areas a_i from each set of concentric contours progressing from the highest contour level in that set (small area) toward lower contour levels (larger area). At high levels, if the area enclosed in a contour is smaller than a given threshold a_b , that contour is ignored. This corresponds to disregarding any structure that is too small to be a microcalcification in visual interpretation. Likewise, the sequence stops when a contour encloses an area larger than a threshold a_u , corresponding to disregarding any structure that is too large to be a microcalcification. In accordance with the experience of radiologists performing visual interpretation, we set a_b to the area of a square with a 0.1mm side (16 pixels for an image digitized at 25 microns per pixel), and a_u to the area of a square with a 2mm side (6400 pixels for an image digitized at 25 microns per pixel). Thus, from each peak, the algorithm obtains an area

sequence a_i , with $i=1, 2, \dots, N$, where N is the number of concentric contours with areas between 16 and 6400 pixels.

Three measurements (features) used to characterize a peak are computed from the area sequence a_i of that peak:

1) Departure (d). Malignant microcalcifications appear sharper than other structures of similar size and shape in normal breast tissue. The departure quantifies the sharpness of a microstructure, with higher values of d corresponding to sharper microstructures. A very sharp microstructure is a peak that departs abruptly from its surround, and has an abrupt increase in the rate of change (slope) of the sequence a_i as i approaches N . A low departure peak has a gradually increasing a_i sequence for i near N . Therefore, the value of d is set to the highest relative increase in the first difference sequence of a_i and the corresponding level is labeled as the departure level.

2) Prominence (p) reflects the relative brightness cue that is used in visual inspection. The prominence has an integer value equal to the number of contours above the departure level and it is approximately proportional to the brightness difference between the brightest region of the microstructure and the immediate surround at the level of departure from background.

3) Steepness (s) is inversely related to the average rate of increase in the area sequence a_i of a peak.

The detection algorithm uses the prominence, departure and steepness values of a peak to determine if that peak is a microcalcification.

Results and Discussion

The detection performance is measured in terms of the true positive (TP) rate and the false positive (FP) rate of detection of clusters of microcalcifications. The algorithm detected all of the clusters in the test mammograms and was able to reject other structures and film artifacts in the central parts of the test mammograms. In the image segments that we analyzed in this study the algorithm did not detect a false cluster. We are currently acquiring a larger data set to evaluate further the sensitivity and specificity of the algorithm.

Our approach is to develop a tool to assist radiologists in determining the location of suspicious clusters. In addition, it will provide the possibility of investigating subtle signs of early breast cancer that may be overlooked visually. This additional capability is the result of essential advantages of the automated machine vision system compared to visual interpretation, including higher spatial resolution and quantitative, repeatable estimates of the location, brightness, morphology and spatial distribution of relevant structures in mammograms, free of the vagaries of human visual processing.

We are currently investigating the potential for further improvement of our results by inclusion of morphological parameters at the microcalcification and cluster levels, in

the algorithm. We are also trying to provide the radiologists with a confidence measure that will be of assistance in assessing the reliability of the algorithmic results and accord with the visual interpretation of the radiologist. We believe that the reliance of this detection algorithm on raw data only is an important factor allowing radiologists to understand and benefit from algorithmic detection results.

Acknowledgements

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SESSION 6

**Information Management/
Teleradiology**

Chair: Charles Flagle

Realtime Requirements and Technical Support for Image Communication in Medicine

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I. INTRODUCTION

Realtime behavior of medical image communication constitutes not only an indispensable need, but also a technological challenge for various areas of clinical and inter-institutional applications. Application domains of broad interest may be categorized as follows:

Cooperation scenarios such as remote expert consultation, education, conferences or patient presentation benefit from realtime image transmission by a synchronized and consistent joint view onto and manipulation of medical images at the different locations of cooperation partners, or by remote realtime presentation of the subject of medical interest (e.g. live pursuing of an operation).

Remote access to medical image data sets for diagnostic or therapeutic purposes should be performed in the second- or subsecond range in order to support an interactive style of work, and thereby flexible and immediate access to relevant patient information in the context of patient care.

Remote manipulation and presentation of prerecorded moving medical images such as cardiac catheter films or ultrasound recording sequences are inherently realtime-oriented. Realtime transmission helps avoiding system reaction latency at application invocation time as well as buffering of enormous amounts of data at the presentation side.

Driven by the increasing performance of digital systems for image generation and capturing, digital communication networks, digital storage systems and graphic workstations, the technological basis for realtime image transmission is going to shift from analog video technique to all-digital systems. While the quality constraints and artifacts of analog technology can mostly be overcome with digital technology, the demands for synchronous or isochronous transmission in the multimegabit-per-second range still constitute requirements being met by only few digital communication concepts.

This paper provides a taxonomy of different network standards and technologies with respect to their suitability for realtime-oriented communication in medicine and gives an example for its utilization.

II. ISOCHRONOUS AND NON-ISOCHRONOUS COMMUNICATION

Isochronous communication is characterized by the fundamental requirement to preserve the time relationships between two events happening at some places, when they are reproduced by transmitting data adherent to these events to some other places.

Having fast¹, and with respect to the data volume to be transmitted, powerful communication systems at disposition, isochronous communication is the preferable mode for

- remote user² interaction with virtually no technology-originated delay, and for
- steady transmission of information which incorporates continuity.

The different genesis of isochronous and non-isochronous communication³ techniques has for a long time been a major obstacle for a convincing, comprehensive technical approach to patient data integration and communication. Patient data are, in many cases, multimedia data. Patient data communication may involve video supervision, remote film viewing, recording or listening to audio annotations or fast image browsing. Remote expert consultation may incorporate realtime human-to-human communication. On the other hand, there are requirements on different degrees of data correctness, which may range up to very high demands. A wrong pixel value of a medical image clearly has an other effect than a wrong character in a patient identifier.

Common and flexible handling of isochrony and data correctness demands can be achieved only by technology concepts and realizations integrating isochronous and non-isochronous communication modes. With ISDN, ISDN-B forerunner networks such as BERKOM [BERKOM87],[Ricke, Kanzow 91], highspeed WAN, MAN and LAN standards such as SDH, DQDB and FDDI as leading-edge networking concepts, with comprehensive multimedia object architectures and multifunctional terminals some technological components following this integrated approach are emerging. However, a complete, standardized communication model capable to substitute the purely "asynchronous" and "point-to-point" OSI Reference Model, is still due.

The following paragraphs give a brief overview over typical isochronous, non-isochronous and mixed mode⁴ broadband application services relevant to health care.

¹that is, with low data propagation delay.

²users of a communication systems can, of course, be both humans and machines.

³isochronous technology has traditionally been a domain of the telecommunication world dominated by PTT organizations, whereas non-isochronous data communication, coming up with the interconnection of computer systems, is strongly influenced by the computer industry.

⁴comprising isochronous and non-isochronous components.

Isochronous Broadband Application Services

In health care isochronous broadband applications focus on image transmission under real time conditions. On the technology level, application services can basically be distinguished by their utilization of analog or digital recording, storage and transmission equipment.

Video Communication Based on Analog Components

Analog video equipment is used in operation theaters, examination rooms, outpatient departments, wards, conferencing rooms. Connection modes are mostly point-to-point and sometimes multicasting (conferencing). Supported activities are

- remote expert consultation
- education (e.g. live pursuing of operations)
- conferences
- patient presentation, supervision
- remote diagnosis.

Analog video capturing, storage and communication can mostly be realized on the basis of commercially available off-the-shelf technology. Hence, the main problem that experiments have to cope with is rather the integration of video systems into the user's environment than the technology itself. Three fundamental conditions have to be matched:

- sufficient image quality. This condition is strongly dependent on the exact application situation and is mainly determined by the endsystem equipment application and environmental conditions (e.g. camera placement and handling, lighting in an operation theater). On the transmission path, sometimes digital transmission systems comprising suitable CODECS (e.g. the VBN network in Germany) are applied to avoid image quality degradation.
- access to all relevant partners. This condition concerns the design of the experiment as well as network characteristics (multicasting capability, on-demand mode capability, conference management capability)
- equipment and its handling must not hinder work.

Fully Digital Video Communication

Fully digital video communication systems emerge from the synergy of digital medical imaging modalities producing medical films⁵, digital image processing systems and highspeed digital networks. Real-time based transmission of angiogram films and echocardiography image sequences are requirements of remote diagnosis in cardiology.

⁵e.g., digital angiogram systems or digital echocardiographs.

Digital film transmission and handling must offer the basic functionality available by conventional film projectors (play, reverse play in different speeds, freeze) and preserve the main advantages of digital transmission, that is, original image quality (e.g. 25 frames/s, 512 by 512 pels/frame, 8 bit/pel) and error-correction, necessary for further image processing.

The main problem of real-time based digital film transmission is still the availability of system components powerful enough to fulfill the performance requirements derived from the above. Experimental realizations therefore are not yet realized, but under development.

Non-Isochronous Broadband Application Services

The scope of applications based on non-isochronous broadband communication can be subdivided into medical image and multimedia document exchange and distributed graphic user interfaces.

Medical Image and Multimedia Document Exchange

Literature reviews show that medical image transfer is the subject of far most activities concerned with broadband communication in health care. Again, most of them deal with PACS methods and technology, which are intra-clinical, usually LAN-based systems.

However, medium and high speed broadband public networks allow for experiments targeting in remote expert consultation, remote diagnosis, education and image verification, which rely on a fast, more or less interactive exchange of images and image sets on the long haul⁶.

As a general real time requirement one may state that interactive access delay to an individual image should not exceed a few seconds.

Distributed Graphic User Interfaces

State-of-the art graphic user interfaces (GUIs) obviously discharge medical users from coping with cryptic, system-specific and user-unfriendly interaction with computer systems and allow for presentation and handling of more complex data structures and functionality than text-oriented systems do.

Distributed GUIs additionally allow to export functionality from one system to another, or, in other words, to distribute functionality on a set of interconnected systems without limiting the global accessibility.

Considering the fact that there are many non-standard applications, e.g. in image processing, developed, maintained and in operation only in individual clinics, the advantages of this technique for the medical community become evident.

⁶these activities are also termed as "teleradiology" in some publications.

The GUI components themselves usually are not too demanding in terms of realtime requirements, but as they allow for a very simple and effective manipulation of voluminous medical data such as radiological images, results of such operations (zooming, moving around a magnifying glass, greyscale transformations etc.) should be generated and presented in realtime, i.e. with delays in the subsecond range.

Mixed Mode Application Services

Mixed mode services join the capabilities of isochronous and non-isochronous communication. In health care application they are utilized by workplace videoconferencing applications.

Workplace videoconferencing requires two interconnected multimedia workstations capable of asynchronous data transfer in parallel with videocommunication⁷. State-of-the-art multimedia conferencing workstations also provide cooperation facilities such as the communication of user input from keyboard, pointing devices etc., and access-controlled and synchronized operations on shared data objects, which are displayed on both communicating workstations. A unique graphic user interface integrates data processing and conferencing service elements.

There are different concepts to realize workplace videoconferencing. For instance, shared data objects can be held on one system and accessed by a distributed graphic user interface existing in two instances on the two workstations, or shared data objects can be duplicated and processed in parallel on the two systems, or entire screen images are copied continuously in videomode from one station to the other. Which concept is realized, heavily impacts the requirements towards the underlying network, and should be decided according to the given resources.

In health care workplace videoconferencing is an appropriate technical basis for applications such as remote expert consultation, remote diagnosis or cooperative therapeutic decision-making.

III. AN APPLICATION SCENARIO: COOPERATIVE THERAPEUTIC DECISION-MAKING IN CARDIOLOGY

Before undergoing a specific therapeutic procedure such as balloon dilatation (PTCA) or surgery at a large hospital or a specialized center, patients suffering from coronary heart diseases usually have been showing up at smaller hospitals or cardiologists in private practice. There different examinations were performed, findings indicating the need for therapy were established, and the decision to refer the patient to the specialized center was made.

One procedure playing a key role in this therapeutic decision-making is the

⁷in some cases where no medical video information is exchanged, instead of video communication only audio communication is required.

echocardiographic examination. However, while echocardiography systems are in place at almost every small hospital or cardiologist in private practice, a well-founded decision about the if and how of, for example, a particular surgical intervention often requires the eye and the judgement of a clinical cardiologist or heart surgeon. The decision-relevant examination, on the other hand, is originally performed at the location of the cardiologist in private practice and - at least in some European countries - the cardiologist in private practice retains responsibility for the therapeutic decision. In this situation it would be very helpful if the data originating from the echocardiograph could be simultaneously viewed by the examiner and the -remotely located - clinician and if a window-based desktop conference facility would allow for audio conversation, for additional presentation of other diagnostic material (e.g. ECGs, chest X-rays, findings) and provide adequate data manipulation functions such as pointing or marking of objects of interest, iconizing of windows, altering the window stacking order and editing of annotations.

From the network technologist's point of view, realization of this scenario might be a demanding task:

- echocardiography images are moving images. They must be presented in real time simultaneously at both ends of the link, and supposed that the examination is still going on, the transmission delay must be virtually zero.
- echocardiography images are very quality-sensitive. Therefore advanced echocardiographic devices produce digital images, which should not be compromised in quality by analog transmission components.
- (Doppler) echocardiography images may be color coded, and an additional voice channel (next to the conversation channel) may be required for the transmission of an acoustic representation of blood flow dynamics.
- access to additional chest X-rays, which may reside in patient records on either side and which constitute large data volume radiographs, should be synchronized between the users and not exceed a few seconds.

The attempt to model this scenario with current information and communication technology reveals that different notions of "realtime requirements" are addressed. In the following we introduce three basic categories.

IV. A SIMPLE CLASSIFICATION OF REALTIME REQUIREMENTS

Evidently strict realtime requirements have to be fulfilled wherever isochronous data transmission is needed to provide a communication service. As the data to be transmitted is structured as a sequence of frames or cells on the transmission medium, the communicating instances have - from the user's point of view - to ensure the smallest possible constant delay for the transmission of these frames or cells.

The order of this constant delay in conjunction with the data volume to be transferred per time unit can be considered as a guideline for the applicability of technology concepts allowing to compensate for disadvantageous network properties such as temporary transmission capacity bottlenecks, jitter between different channels

or time-consuming coding/decoding procedures. As far as the constant delay value allows, frames may arrive before time (i.e. before they are expected), and various buffering and synchronization techniques may be applied to achieve information processing at the receiver's end right in time.

This consideration gives reason to distinguish two classes of applications w.r.t. their realtime requirements:

- applications requiring *isochronous transmissions in live mode*
- applications requiring *isochronous transmissions in replay mode*

Applications requiring isochronous transmission in live mode appear in all situations where the time delay between the origination of data at the sender's end at its processing at the - - remote - receiver's end has to be virtually zero. Typical examples are live pursuing of an operation for educational purposes, or remote diagnosis, where the physician monitors and controls the course of a remotely performed examination. The very rigid realtime requirements of such applications do not only limit the possibilities of buffering policies to overcome network properties such as channel jitter, but constitute also a higher demand on the robustness of the network: Information that is not transmitted immediately and reliably, must be considered "lost".

Many applications, however, do require isochronous transmission but are in principle tolerant to a certain conceivable transmission delay: These are applications where the time relationships between the data frames (e.g. film frames) have to be kept in order to preserve the information, but where no interactions between sender and receiver are required, or where the information source is a storage medium allowing for halting and replaying of parts of the data stream according to the user's needs. Since the latter case seems to be predominant, we termed them applications requiring isochronous transmissions in replay mode. In this case, there is a wider scale of buffering and synchronization policies applicable, and, as far as time allows, retransmission and reconfiguration techniques may be applied to recover from various transmission faults.

But also in case of non-isochronous services realtime requirements may be stated: Here they refer to the highest acceptable system response time, which may be judged as an essential system quality criterion in interactive applications such as radiological image browsing or interactive application of image postprocessing functions. Again, realtime requirements are weaker than for the application classes above: Up to a certain degree deviations from an average access delay are tolerated, since they do not affect recognition of the information represented by the data transmitted.

V. RELATED PROPERTIES OF THE COMMUNICATION SYSTEM

As already indicated, the satisfaction of realtime requirements on data transmission may interfere with a number of different other "first-order" communication requirements in health care which should be included into a taxonomy of suitable network techniques. We consider as most relevant

- the *preservation of information quality on the transmission path*. This requirement addresses problems related to limited available bandwidth and to the choice of the transmission technique, which both affect the coding of information and therefore the potential to obtain at the receiver's end the full information that is available to the sender by the given data set. In the ideal case, coding must not affect the information contents (that means, for example, that compression may only lead to loss of redundant information).
- the *preservation of the required realtime properties also in concurrency with other services running on the same network*. As far as the network structure and topology allows, other services or multiple instances of the same service should be able to run concurrently without affecting provision of the service in question. This allows for a better integration of the service in question into a given communication environment and for an easy replication of the service.
- the *robustness* of the network, i.e., its ability to act fault tolerant keeping the realtime requirements and to recover in time from errors on the link in less severe cases..
- the *economic usage of given network resources*, that is, the possibility to assign unused resources (e.g. idle channels) to other users according to their needs and
- the *support of information privacy*, that is, the provision of means to prevent unauthorized reading, corrupting, deleting or falsifying of the transmitted information.

VI. TECHNICAL SUPPORT

In the following we present a choice of current standard network technology concepts and a summarizing, qualitative assessment with respect to satisfaction of the above requirements. By looking to which extent these requirements are relevant to a concrete given service, conclusions regarding the preference of one or another networking solutions may be drawn.

For the reason of their image transmission capability, only broadband networks are considered. A suitable conceptual distinction can be made by looking at the different transfer modes and medium access procedures. Relevant standard definitions in this field can be found in the FDDI, FDDI II and DQDB documents for MANs and high speed LANs, and in the SDH and ATM documents for WANs. Additionally, analog video transmission systems (video networks) shall be assessed, since they still

play an important role in medical image communication.

Though on the first glance this collection of network types seems to lack comparability, from our own experience in the BERKOM project we feel that at least in the coming years the user will have the option to choose: at least between interconnection of his equipment via LAN or via broadband PABX in the local area, and between interconnection with remote partners via bridged LANs or direct access to a MAN or WAN, which already extends the scope of network types to the given set. No question that this set is incomplete.

FDDI

FDDI [ANSI 87/88] stands for *Fiber Distributed Data Interface* and denotes a LAN type based on fiber optic point-to-point links. These links together with the respective network stations form a token ring LAN running at 100 Mbps over a maximum distance of 100 km with up to 500 stations connected. By a double ring layout a certain provisions at the stations, FDDI has certain self-reconfiguration capabilities in case of cable breaks or station faults. The operation mode of FDDI is purely packet-oriented. The definitions cover the physical layer and the MAC sublayer.

The double ring configuration and the self-reconfiguration capabilities give the system an excellent robustness even under real time conditions, while the limited bandwidth may lead to a quality reduction in isochronous transmissions may have to be tolerated and, because of the fair medium access and the missing bandwidth reservation facility, concurrent activities may badly affect the throughput of an individual transmission. As with other LAN type networks, the shared medium allows for an excellent economic usage of the network resources, but at the same time requires additional measures to protect the exchanged information against unauthorized reading.

FDDI II

As a spin-off and a functional enhancement of FDDI, FDDI II [ANSI 90] has special features to additionally handle synchronous PCM channels ("*wideband channels*"), which can individually be assigned to requesting stations for a certain time and which can be used in circuit switched mode (for isochronous traffic) or in packet switched mode. To ensure that bandwidth for isochronous traffic is always available, isochronous traffic is serviced with highest priority (out of 4 priority levels). The next lower priority is reserved for packet mode traffic with a delay limited to the double of the target token rotation time.

Compared to FDDI FDDI II looks somewhat better as far as the throughput of isochronous transmissions is concerned. Wideband channels can be reserved for isochronous traffic. This results in a better information quality preservation for stations which are successful to get hands on a number of wideband channels, but in

an even worse concurrency situation for stations which need to communicate, since they now have to share the remaining bandwidth with other stations.

DQDB

The DQDB (*Distributed Queue Dual Bus*) standard IEEE 802.6 [IEEE 89] covers the physical layer and the MAC sublayer of the OSI layer scheme. It defines a system consisting of two parallel, counter-rotating unidirectional buses, to which all participating nodes are connected. All nodes read data passing by on both busses, and write on each one in a "downstream" direction. One or two nodes, respectively, serve as head and tail of both busses. Information on the buses is organized in synchronized frames, which are again divided into a number of slots. Framing and slots are generated by the heading node(s), and dropped by the tailing node(s). In case of a physical rupture the network can be dynamically reconfigured by assigning the head-of-bus and tail-of-bus functions to the nodes nearest to the rupture. Preallocation of a variable number of slots by the heading station(s) allows for the reservation of bandwidth for isochronous transmission. Though the standard does not prescribe a specific transmission rate, values of 155 Mbps (targeted to the level 1 of SDH), 45, 34 and even 1.5 Mbps are accommodated. At the other end of the scale, also a transmission rate of 620 Mbps, according to the SDH level 4, is envisaged [Mollenauer 89].

Among the network types considered, the characteristics of DQDB are most similar to FDDI II. However, the possibility to run DQDB with higher speeds than just 100 Mbps reduces the information quality preservation and concurrency problems.

ATM

The *Asynchronous Transfer Mode* [CCITT 89 b] is the prospective transfer mode of the future global broadband ISDN. It defines a fast connection-oriented packet switching technique with packets or "cells" of fixed length. ATM supports both isochronous and non-isochronous, steady and bursty, connection-oriented and connectionless traffic by the introduction of a so-called "adaptation layer", which defines four different service classes with suitable properties. In contrast to traditional packet-switching WANs, ATM supports also multicast and broadcast transmission. Endsystems can be connected to ATM switches via dedicated lines or shared media such as MANs. As with DQDB, ATM is not dependant on a specific transmission rate, but SDH-oriented rates (155 Mbps, 622 Mbps) are or will be recommended by CCITT.

Compared with the LAN and MAN standards, for the medical user ATM has the big advantage to discharge him from the concurrency problem since he can connect his ATM endsystem to a dedicated line. The problem of cumulative bandwidth requirements is referred to the network provider who may solve it by sufficiently

powerful switches and an appropriate network topology. Moreover, the personally available bandwidth may be chosen according to the user's needs. An additional advantage is the higher degree of privacy on the dedicated subscriber line. However, since erroneous routing of cells is not precluded, some information might arrive at an unauthorized receiver. A dedicated subscriber line is a weak point in terms of the robustness of the link, but on the other hand a fault on this line does not impact other parts of the network. A similar aspect holds w.r.t economic usage of the network resources: Again the dedicated subscriber line is the weak point, but it can be replaced by a shared medium if desired.

SDH/STM

The *Synchronous Digital Hierarchy* [CCITT 89 a] defines a number of transmission rates ranging from 155 Mbps up to 2488 Mbps and related multiplexing schemes, which can be applied to set up highspeed circuit switching networks (*Synchronous Transfer Mode* (STM) networks) or can establish the basis for the transport of ATM cells.

In the former case, simplicity of the transfer mode and channel structure has the advantages to solve information quality preservation problems by assignment of an appropriate static bandwidth to the link, what might be acceptable for isochronous transmission of PCM-coded video information, but is an enormous waste of resources when traffic becomes bursty. Moreover, the robustness of a link may suffer from the static routing scheme. The privacy of patient data, on the other hand, can excellently be maintained.

Video Networks

As a last class of networks we should briefly look at video networks with analog transmission technique. Such networks usually provide a number of frequency or time division multiplexed fixed bandwidth channels for the transmission of composite video signals such as FBAS or NTSC.

Their essential disadvantages are the inherent loss of information quality on the link and the lack of privacy, since the decoding of composite signals is relatively simple. Moreover, with SDH/STM networks they share the drawbacks of a low robustness and a poor economy, where slight differences origin from the more effective information encoding and the higher exposure to interferences.

The following table provides a synopsis of the above taxonomy:

	Video Networks	FDDI	FDDI II	DQDB	ATM	SDH
1 Isochronous transmission in live mode						
Information quality preservation	-	o	+	++	++	++
Concurrency with other services	+	-	--	o	++	++
Robustness (fault tolerance)	--	++	++	++	+	-
Economic usage of resources	+	++	++	++	+	o
2 Isochronous transmission in replay mode						
Information quality preservation	-	o	+	++	++	++
Concurrency with other services	+	-	--	o	++	++
Robustness (fault tolerance)	-	++	++	++	+	-
Economic usage of resources	+	++	++	++	+	o
3 Limited delay						
Information quality preservation	--	+	+	++	++	++
Concurrency with other services	+	o	-	+	++	++
Robustness (fault tolerance)	-	++	++	++	+	o
Economic usage of resources	--	++	++	++	o	--
All (1-3)						
Privacy	--	o	o	o	+	++

excellent ++ good + fair o poor - bad --

VII. CONCLUSION

The above classification of realtime requirements and the taxonomy of networking concepts may give us some advice w.r.t the technological basis for information exchange in cooperative application scenarios in health care.

Looking at the example introduced in section II, all three classes of realtime requirements are present: isochronous transmission in live mode in case of an ongoing examination; in replay mode when an already captured image sequence shall be cooperatively viewed; transmission with limited delay of additional radiological images and other patient data. Information quality preservation is extremely important, and privacy is also required since the cardiologist in private practice and the clinician do not reside in the same trusted environment such as the same hospital. For these reasons a SDH/STM link is a suitable solution supposed that resource economy is not a key problem. Resource economy may come into play when, for example, the specialized center begins to act as a service center for a larger number of cardiologists in private practice. Then the specialized center should subscribe to an ATM network and connect the desktop conferencing station(s) directly to the ATM subscriber interface rather than doing this via an FDDI or DQDB LAN.

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A Plan for Operational and Financial Justification of PACS

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With clinical and technical validations of PACS proceeding apace, planning has begun for the operational and financial justifications. The aim is to prepare a complete and rigorous description of both the present and planned methodologies. Such a database will become the basis for establishing the chronology of equipment introduction, expectations for operational enhancements, and forecasts of cash flows.

The physical dispersion of radiology resources requires that each of 19 locations be described with magnitudes for as many of the 41 chosen parameters as apply (see Table 1). This matrix will then be used to predict the same parameters with PACS installed. A large labor cost savings from PACS is expected to occur in film library storage and retrieval activities. Since some locations have library personnel performing non-library tasks, careful observation and analysis will be required to prevent an over-estimation of savings (theoretical vs realistic FTE reductions).

At each location, a detailed flow chart for film and paperwork is constructed (see Figure 1). Lead technicians, supervisors, and managers must unanimously concur on each chart's accurate representation of the departments' daily realities. In essence this is an operations audit to clarify the differences between official policies and actual procedures. Process flow charts may be used selectively where methods improvement opportunities exist.

One of the most powerful indicators of quality management is the diagnostic cycle time (DCT = duration from "patient exam" to "report available"). PACS is expected to cause a significant reduction of DCT. An image management pilot study is underway which will permit comparison of actual DCT's before and after introduction of digital image management.

In pursuit of an operational justification for PACS at The Johns Hopkins Hospital, we are using our Radiology Information System records to provide most of the data which defines the DCT (see Table 2). A few components may need direct observation for accurate duration measurement. Statistical analysis of different variable groupings will disclose pre-PACS conditions for comparison with corresponding PACS data. Table 3 shows a preliminary analysis for format display

only. It uses a small data sample and is not indicative of the present system's actual performance.

The need for such detailed benefits analysis of PACS is due to several factors. Foremost is the shortage of resources in healthcare. Soon, the lack of thoroughness of a justification's methodology may alone be sufficient cause for denial. One such danger is an apparent claim for cost savings which could be achieved with techniques other than a PACS installation. Another danger would be to list theoretical labor savings as achievable without taking into consideration known organizational constraints and past practice.

A second factor is the sheer size of a teaching hospital radiology department. A complete map of resource distribution during a defined base period preserves an auditable benchmark for cost analysis. PACS is likely to be installed gradually over several years. This could stimulate an FTE "migration" to remaining non-PACS radiology sections. These areas might then display an overestimated labor savings for PACS justification. Conversely, if resource limitations result in an understaffing of a section, the savings of a PACS installation may be underestimated. Such possible distortions are best prevented by a very detailed description of all operations within the Radiology Department.

Another factor is the increasing need for consistent and traditional management terminology and methodology. As new program costs exceed available resources, business-like cost/benefit-based decision support will develop. Those justifications which embrace it first will fare better.

Operational Hours	Backlog
Exam Volume	Fulfilled Qty.
Maximum	Not fulfilled Qty.
Average	Duplications
Minimum	FTE's (day/eve/night)
Imaging Units	MD Radiologist
Section Space	MD Other
Reports Generated	RN
Diagnostic Cycle	Technologist
Average Duration	Clerk/Aide
Task Content	Secretary
Radiologist	Escorts
Non-Radiologist	Supervisor
Transports	Manager
Professional	Other
Referring MD's	Equipment Cost (Image Related)
Messengers	Hospital Owned
Patients	University Owned
Film Copies Made	Rented
Steady-State Film Qty.	Consignment
Film Library Space	Depreciation
Film Purge Interval	Space
Library Media	Maintenance Cost
Retrieval Requests	Electrical Consumption
Quantity	Film Cost
Task Content	Film Jacket Cost
Cycle Duration	Supplies Cost

Table 1. PACS justification parameters.

DATABASE FOR IMAGE MANAGEMENT PILOT STUDY

DATABASE NAME	TABLE 2.	DEFINITION
History No.		8 digit patient ID number
Accession No.		5 digit accession number (ANNN)
Exam Date		date exam was performed (YYYYMMDD)
Name		patient's name
Age		patient's age group (see table)
Sex		patient's sex (M/F)
Status		inpatient (I) or outpatient (O)
No. of Exams		no. of exams performed on a patient on a given day
REV Center		revenue center code
Procedure		code for type of exam performed (must be used with revenue center)
Shift		time period in which exam performed
Examstart/Examstop		time patient in and out of exam room (HHMM)
Section		area of radiology where exam was performed
Attending MD		attending physician's ID code
Requesting MD		requesting physician's ID code
Radiologist		radiologist's ID code
Requestloc/Location		code and description of area from which the patient was sent (inpatient=floor, outpatient=clinic)
ICD9/TXT		code and description of reason for exam
Verif Status		verification status (V=verified, I=incomplete, A=amended, U=not verified)
Verif Date		date report verified (YYYYMMDD)
Verif Time		time report verified (HHMM)
Repeat		code for reason exam was repeated
Reptype		status of report (3=full report, O=not read)
Billtype		DB=debit, CD=credit, DX=no charge, RO=read only
RVU		RVU amount
FUD		functional unit director (divisions of hospital according to specialists)
Dictation Date		date dictation completed
Dictation Time		time dictation completed
Transcription Date		date transcription completed
Transcription Time		time transcription completed
Length		time duration of dictation in tenths of minutes
History No.		patient ID number
Radiologist		radiologist's ID code

TABLE OF AGE BY TIME

AGE	TIME												
FREQUENCY PERCENT ROW PCT COL PCT	WITHIN 1 DAY	>1 TO 2 DAYS	>2 TO 3 DAYS	>3 TO 4 DAYS	>4 TO 5 DAYS	>5 TO 6 DAYS	>6 TO 7 DAYS	>7 TO 8 DAYS	>8 TO 9 DAYS	>9 TO 10 DAYS	MORE THA N 10 DAY	TOTAL	
1 AND UNDER	538 4.19 29.76 9.10	647 5.04 35.79 19.31	317 2.47 17.53 22.51	126 0.98 6.97 18.10	45 0.35 2.49 12.33	35 0.27 1.94 16.91	18 0.14 1.00 13.74	10 0.08 0.55 10.99	8 0.06 0.44 14.29	5 0.04 0.28 10.87	59 0.46 3.26 10.12	1808 14.08	
5-14	463 3.60 36.26 7.83	424 3.30 33.20 12.65	168 1.31 13.16 11.93	78 0.61 6.11 11.21	42 0.33 3.29 11.51	19 0.15 1.49 9.18	14 0.11 1.10 10.69	9 0.07 0.70 9.89	7 0.05 0.55 12.50	6 0.05 0.47 13.04	47 0.37 3.68 8.06	1277 9.94	
15-24	558 4.34 53.81 9.44	221 1.72 21.31 6.60	101 0.79 9.74 7.17	39 0.30 3.76 5.60	26 0.20 2.51 7.12	14 0.11 1.35 6.76	9 0.07 0.87 6.87	7 0.05 0.68 7.69	2 0.02 0.19 3.57	3 0.02 0.29 6.52	57 0.44 5.50 9.78	1037 8.07	
25-34	920 7.16 58.01 15.57	285 2.22 17.97 8.50	135 1.05 8.51 9.59	61 0.47 3.85 8.76	43 0.33 2.71 11.78	28 0.22 1.77 13.53	8 0.06 0.50 6.11	2 0.02 0.13 2.20	4 0.03 0.25 7.14	4 0.03 0.25 8.70	96 0.75 6.05 16.47	1586 12.35	
35-44	905 7.05 50.50 15.31	410 3.19 22.88 12.24	166 1.29 9.26 11.79	96 0.75 5.36 13.79	41 0.32 2.29 11.23	29 0.23 1.62 14.01	17 0.13 0.95 12.98	19 0.15 1.06 20.88	5 0.04 0.28 8.93	5 0.04 0.28 10.87	99 0.77 5.52 16.98	1792 13.95	
45-54	739 5.75 45.31 12.50	442 3.44 27.10 13.19	166 1.29 10.18 11.79	86 0.67 5.27 12.36	51 0.40 3.13 13.97	22 0.17 1.35 10.63	23 0.18 1.41 17.56	12 0.09 0.74 13.19	10 0.08 0.61 17.86	4 0.03 0.25 8.70	76 0.59 4.66 13.04	1631 12.70	
55-64	728 5.67 47.06 12.32	388 3.02 25.08 11.58	161 1.25 10.41 11.43	95 0.74 6.14 13.65	55 0.43 3.56 15.07	25 0.19 1.62 12.08	18 0.14 1.16 13.74	12 0.09 0.78 13.19	6 0.05 0.39 10.71	10 0.08 0.65 21.74	49 0.38 3.17 8.40	1547 12.04	
65 AND OVER	1059 8.25 48.89 17.92	534 4.16 24.65 15.94	194 1.51 8.96 13.78	115 0.90 5.31 16.52	62 0.48 2.86 16.99	35 0.27 1.62 16.91	24 0.19 1.11 18.32	20 0.16 0.92 21.98	14 0.11 0.65 25.00	9 0.07 0.42 19.57	100 0.78 4.62 17.15	2166 16.86	
TOTAL	5910 46.01	3351 26.09	1408 10.96	696 5.42	365 2.84	207 1.61	131 1.02	91 0.71	56 0.44	46 0.36	583 4.54	12844 100.00	

FREQUENCY MISSING = 597

Patient Tracking in the Radiology Department

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Introduction

The year 1988. A Radiology Information System (RIS) is a well-known phenomenon in the radiology department. Examination registration, appointment scheduling, archive management and reporting functions are in daily use. Billing is done without human intervention [1].

Integration within the Hospital information System (HIS) makes decentralized use of RIS functions possible. E.g. decentralized report printing, on-line insight into patient historical reports and the entry of requests for film-folders from each HIS terminal for authorized users [2].

So what else is there a RIS user could wish?

In 1988 BAZIS decided to extend it's RIS, called RADI, which is in use in 25 Dutch hospitals (in total a little upwards of 2 million examinations per year), with functions for management information, coding of radiological findings and patienttracking. In [3] these functions are described as necessary for a complete RIS. This paper describes the BAZIS/RADI patienttracking system, starting with the aims it should fulfil: to control the patientflow in the department, to give insight into the occupation of examination rooms and staff, but also to gather data for management information [4,5]. Subsequently the realisation is described: what functions has this patienttracking system to offer? Finally, as the RADI/patienttracking is implemented in a number of hospitals, experiences and results will be presented.

Why patienttracking?

In most radiology departments the large waiting room next to the reception desk is replaced by smaller seating

groupings adjacent to examination rooms, affording more privacy and better patientflow. In addition to this the staff and patient circulation paths are separated. Consequence is that the reception personnel nor the further staff have an overview of waiting patients. So the most obvious reason for patienttracking is the demand for quality improvement by monitoring patients and their waiting time.

Other objectives of the development of patienttracking were:

- to support the communication between reception desk and technical staff.
Usually the technologist walks to the reception desk to get information about the patient and the examination: who is the next patient, has my patient arrived, which examinations are planned. Patienttracking should give the technologist insight into this information on the place to work.
- to allow the technical staff to verify and rectify the registered examinations, thus improving the data quality.
- to provide the manager of the radiology department with an overview of the patientflow in the department thus offering the possibility to make rearrangements to ensure that everything runs smoothly.

Realisation of patienttracking requires registration of data according to several events in the patientflow. This registration offers a spin-off for management information, supporting tactical and strategical goals:

- to retrieve the cause of structural delays
- to achieve the best possible room occupation and planning of staff, e.g. by tuning the appointment scheduling system.
- to support the planning of future resource (equipment or personnel) requirements by analyzing trends in the requests for radiologic procedures.

Keynotes

It is well-known that a user-friendly interface is a main precondition for acceptance of computer applications. For this reason marketing people pile words as user-friendly, self-explaining, ergonomics and flexibility until another

page is full. But in practice for most applications the users have no choice: the job must be done. Not so for patienttracking. Patienttracking must be user-friendly, easy accessible and straightforward to use because it is of no primary necessity for the radiology department. If it doesn't fulfil these conditions, it will not be used or the events during a patient's visit will only be partly registered. This will diminish the value of the system for both operational use and the management:

- did this patient not show up or did we just not register his data?
- is this patient really still in the department?
- furthermore it will be impossible to recognize patients that are waiting too long in a list of patients with incomplete data.

Because of the interest of complete and accurate registration a patienttracking system should, in addition to the basic requirements like a user-friendly interface etc., offer some extra features making the system (even) more attractive to use.

Another basic assumption was that the patient should not be troubled with patienttracking, the patient may not even notice that "he's being traced". Of course he may and should notice the benefits like shorter waiting times. Patienttracking should support the individual service to the patient, and not give the impression of being 'just another patient'.

Broad outlines of the BAZIS/RADI patienttracking system

The main ingredients for patienttracking are the registration of five events in the patient flow (the appointment, the arrival on the department, start and end of the examination and the departure of the patient) and a high density of display terminals to give each work location insight into the state of affairs. However some more ingredients are necessary for a successful implementation: a very user-friendly interface, as mentioned above, and some additional value for those users who in first instance don't benefit from the extra work that they are expected to do.

An outline of the patienttracking system is given by describing the possibilities and consequences for the different activities on the radiology department.

Reception desk

On the display terminal on the reception desk a review of the expected patients for this department is shown. When the patient arrives the receptionist can browse through the review, but far more easy is to identify the patient by typing a few letters of the name: the review will automatically center around the bold-printed record of the patient. The arrival of the patient is registered and the patient can go to the appropriate waiting room. It is possible to get further information about the patient by entering simple commands. The requested information is shown in a window, leaving the review intact as much as possible. Furthermore the receptionist can enter relevant indications for the technical staff, e.g. emergency (this will be very clearly visible on the display terminal of the technical staff), wheelchair user, etc.

Technical staff

On the basis of the review on a display terminal the technologist selects which patient is next and by means of a very simple command the start of the examination and later on the end of the examination and the moment the patient leaves the department are entered. The display terminal should therefore be placed close to the examination room, or, even better, in the examination room. The technologist has a different need for patient data than the receptionist, therefore the technologist gets a presentation tuned to his or her demands; in fact each display terminal can have it's own template and sorting. Independent of the chosen template is the indication that maximum waiting times are exceeded: when the waiting time for a patient has passed the limit, the record of this patient is printed bold in the review and in the heading appears an indication. The maximum waiting times are parameterized for every examination room. It takes the technologist one keystroke to get insight into the historical examinations of the patient, to look at future appointments, to enter the (coded) reason for a possible delay, or to review the protocol of a specific study, etc. In addition the technologist can obtain simple statistics about today's production for his or her examination room: number of treated/expected patients and exams, mean duration of the exams, total room occupation, etc. (one of the ways the system can be attractive for the users).

The radiologist

Particularly when display terminals are located in the examination rooms and diagnostic area, patienttracking can be useful for the radiologist. The reviews give easy access to patient data such as reports of previous examinations, especially because the complete historical reports of every patient are kept available on-line for 5-10 years. Of course all previously described facilities are at the radiologist's disposal.

The manager

Patienttracking gives the manager insight into the current situation in the department in two ways:

1. The patienttracking review, with a template and sorting that meets the demands of the manager, gives global information about the throughput in the department.
2. The report function, that allows the manager to make various reports of waiting times, patients with an appointment who did not show up, number of patients per examination room, etc., thus providing the possibility to anticipate on a deviation of the normal routine.

In addition to this the available data can support the long term management of the department. With the BAZIS report generator the manager is able to define for example the necessary time-flow analysis reports as described in [5]. Such a report generator, besides predefined reports, is crucial for the use of a RIS for the support of management decisions [6].

Practical experiences

The first implementation

At the end of 1990 a very dynamic start was made in the Medical Center Alkmaar, a city close to Amsterdam. Display terminals were installed for clusters of examination rooms or in the examination room. The complete staff was trained in a dry run. A careful start was planned, so the reception desk would register every arrival of a patient, but the first few days only one examination room would do the registration of other

events. However, at the end of the first day half the department was working with patienttracking and two weeks later came a request for display terminals in the refreshment room: in the past they had to walk to the reception desk to see whether their patient had arrived, now they even didn't have to rise!

The first problems

The experiences in the hospitals where patienttracking is implemented showed a number of issues one should pay attention to:

- good results are only possible if a sufficient amount of display terminals are installed at the **right** locations; motivation problems in one hospital were solved by relocating some of the display terminals.
- the exact registration of events and involved personnel offers the possibility to investigate the productivity of individual staff members. If the management cannot convince the personnel that this is not the objective of patienttracking, there will be serious trouble on the way [5].
- in connection with the previous point it may turn out to be necessary to give a refresher course after a year or so, to make the purpose and possibilities clear again for all users.
- to support the switch to the new method of working, there is no harm in making the department (so far as it goes) dependent on patienttracking; e.g. make sure the only way to find out which patient is next is the patienttracking review.

The first results

The following observations are recorded from two radiology departments who by now have more than one year of experience:

- analysis of the real duration of exams allowed for a better tuning of the appointment-scheduling system. Within a few months this resulted in measurable shorter waiting times and better occupation of examination rooms (e.g. in one hospital the mean waiting times were reduced from 40 minutes to 20 minutes).
- in case of delays feedback to the waiting patients is possible, with a forecast of the waiting time. This service is highly appreciated by the patients.
- by means of patienttracking the reception desk can

respond immediately to questions from referring departments about the progress of an examination or which technologist or radiologist was in charge of an examination; formerly this would result in an expedition on the department.

- the registered data is more reliable, because of the possibility to verify, rectify or complete the data at the working location.
- 'to put it briefly', one manager said, 'at a single glance I can see what is going on in the department'.

Conclusion

The introduction of patienttracking functions in the radiology department increases the service level to the patient, it improves the throughput of patients and it supports the short and long term management. Or, to put it in a nutshell, it is one step closer to the preferable situation in which each waiting room has only one chair that is never cold.

However, an essential prerequisite to obtain these results is the commitment of the staff-members. This can only be achieved by offering a sophisticated user-interface and some extra features to make the system attractive to use.

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Radiology Information System Design Considerations for Optimal Effectiveness in the Public Hospital Environment

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As Radiology Information Systems continue to grow in popularity, they are being placed into an ever-widening assortment of different types of departments and situations. This can result in the exposure of the software and the hardware to an assortment of unexpected and often unpredictable local factors which can dramatically affect system performance and effectiveness. A given system can function acceptably in one type of hospital environment yet fail miserably in another. This phenomenon serves to underscore the seemingly basic point (which is nonetheless sometimes ignored by vendors and end-users alike) that truly successful RIS implementation requires a system to be compatible with the hospital environment in which it is being asked to perform.^{1,2} One particular environment which can pose some formidable challenges to a system is that of the large public hospital (LPH). The LPH is the environment which can most benefit from a well-implemented RIS, yet it is at the same time the toughest set of surroundings into which a system can be placed. To be successful in the LPH, a system must be able to withstand a variety of afflictions and adversities which are not found in other environments. There are many characteristics of the LPH which have the potential to become significant obstacles to effective RIS use, such as:

- **Inadequate levels of staffing and staff training for the tasks of system operation, maintenance and data validation** - in this era of shrinking public resources and limited hospital budgets, LPH's are often faced with shortages in every personnel category; there often are simply no funds available for dedicated (or even semi-dedicated) system staff

- **The tremendous size and complexity of the patient database, including large numbers of aliases** - the database of the LPH can become filled with tens of thousands of similar and identical names, which are often misspelled; additionally, a significant proportion of patients in the database carry multiple names and medical record numbers
- **The large, constantly-changing groups of referring physicians, radiologists, residents and students** - LPH's are often major teaching centers, with myriads of people rotating through, all of whom must be accurately tracked and accounted for in the system
- **Partial or total incompatibility with existing interfaces and information systems** - an LPH will often have multiple existing information systems with which the RIS will need to interface; achieving a useful interface with these older systems is a decidedly non-trivial task at best, and it is sometimes nearly impossible¹
- **System database corruption as a result of errors in operator input and specious interface data** - in the LPH, the patient database can be corrupted by improper direct data entry, or, more subtly, via incorrect data entering from an interface to another system
- **The potential for sabotage (of both the mischievous and malignant varieties) of the database, the software and the hardware** - employee fear of change which always accompanies the introduction of automated methods, coupled with the existing substrate of resentment stemming from across-the-board job cutbacks (which have been necessitated by bare-bones LPH budgets) combine to make system sabotage a real possibility
- **Antiquated, inflexible work rules and job descriptions** - often grounded in outdated manual methods, they help to

prevent the system's potential benefits from being fully realized

- **The need for a simplified means of continuous capture of time-critical data under conditions which are often hectic** - LPH's often have tremendously busy, trauma-oriented emergency departments; it is in this setting that a system often receives its severest tests
- **The lack of trained in-house transcriptionists** - LPH's frequently cannot compete with the private sector for these valuable individuals; often, large numbers of reports must be sent outside the hospital for transcription

In order for a system to address these problems and thereby be a useful tool while operating in the LPH environment, its basic design philosophy must allow it the flexibility to adapt to the wide variations in needs, abilities and motivation to be found among its users. It must also be able to work well with a minimal "supporting cast." Among the specific features such a system should possess are:

- **Simplified, straightforward hardware and software design to facilitate operation and maintenance by non-dedicated personnel** - in the LPH environment, trained computer support people are at a premium, and few hospitals and radiology departments of this type can afford the luxury of a cadre of dedicated system personnel who can devote major portions of their time and energy to the "care and feeding" of the system; therefore most system-related chores (other than tasks such as back-up, which can be automated) have to be done on an as-needed basis by non-dedicated personnel in their "spare time")
- **An object-oriented graphical user interface** - this would greatly reduce training time and also allow personnel of all skill levels to use the system more accurately and dependably

- **Features which are germane to the LPH environment** - Many system features which are useful in other settings are thoroughly inapplicable (and sometimes deleterious) in the LPH environment
- **Extensive automatic data validation, error-checking and self-auditing capabilities** - this would help prevent contamination (both accidental and intentional) of the database, as well as allow for simple management pinpointing and troubleshooting of problems; additionally, anti-sabotage security measures would be easier to implement
- **Simplified capture of patient and exam data** - in the hectic LPH environment, where short-staffing has unfortunately become a way of life, this would help insure proper (and medicolegally-correct) tracking of patients, exams and films; the already-overburdened clerical and technical personnel can only enter accurate, timely data if the means to do so is transparent and straightforward
- **Simple on-line radiology report correction by radiologists** - given the scarce in-house typing resources in many LPH's, the system should allow radiologists the option to quickly and easily make corrections to reports themselves with just a few keystrokes or mouse clicks, thereby eliminating the need for another iteration of the corrected report through the (often remote) typist
- **Simple, flexible ad hoc management report generation** - department and hospital management should have the ability to quickly and easily extract needed data from the system themselves via a streamlined and user-friendly SQL interface; this would obviate the need for them to either require the services of trained personnel to access the database or have to learn an arcane report generation system themselves to do so

- **Comprehensive and flexible radiology report print batching and spooling control** - the ability to print patient reports in ad hoc batches is quite important, and it should be accessible and easy-to-use; also, in a large decentralized LPH radiology department, it is important for there to be full, unambiguous two-way communication between all of the remote printers and the central computer, with automatic verification and logging of all printing that occurs (and, equally important, doesn't occur)
- **Rapid phonetic name search with provision for easy access to multiple patient aliases** - this is essential for prevention of contamination of the integrity of the database by overstressed clerical personnel
- **Easy-to-use application-level messaging** - this would serve, especially in large decentralized departments, a number of important purposes
- **Simple, straightforward microcomputer connection to the RIS** - this would enable authorized people in the department (who need not be system experts) to download information from the RIS for use in teaching, quality assurance and other necessary activities
- **An RFP which is tailored to the LPH** - the RFP should be explicitly structured to reflect the specific concerns and features which are of concern in the LPH environment;³ an aid to this process would be the performance of a pre-RFP procedure audit of the LPH by a prospective vendor; this would enable the hospital to evaluate the vendor's depth of understanding of the unique problems of the institution
- **Progressive, forward-thinking, cooperative RIS vendor** - selection of a vendor with a sincere ongoing commitment to innovative R & D in the LPH setting is crucial; equally crucial is the vendor's ability and willingness to supply

high-level support to the LPH on a continuing basis, recognizing the fact that no RFP can ever be totally prescient regarding the kinds of problems which may be encountered down the road^{2,3}

No single currently-existing commercial system embodies all or even most of the above desired characteristics. The great challenges to effective system use in LPH's, combined with the equally-great need for the benefits which a system can potentially bring to these institutions, make them powerful proving grounds for new ideas and directions in RIS development. The use of Artificial Intelligence techniques in system design may aid in the realization of many of the design objectives mentioned above, particularly in the areas of data validation and database integrity.

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Image Communications: Where Are the Limits?

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ABSTRACT

As diagnostic radiology continues to move in a digital direction, the requirements for data delivery systems that transfer and display high-resolution images at satisfactory rates continue to challenge technological limits. In many cases image transfer and display make up a significant portion of the workload associated with a digital image viewing system. Different operational environments have different image delivery requirements, therefore a family of solutions is necessary to address image communication needs within the medical center, and among hospitals, clinics, and physicians' offices.

The electronic radiology image and information testbed at the Mallinckrodt Institute of Radiology utilizes local area communications technologies based on Ethernet, FDDI and private branch exchange ATM. Wide area communications experiments include narrow-band ISDN, T1 and ATM at rates ranging from 64Kb/s to 100 Mb/s. Performance comparisons, based on analysis and measurements, are presented.

INTRODUCTION AND BACKGROUND

A number of Picture Archiving and Communications Systems experiments, testbeds and operational installations have been described.¹⁻⁴ The goal of the testbed activities at the Mallinckrodt Institute of Radiology has been to create tools and conduct experiments useful in gaining an understanding of the technologies and architectures appropriate to solving the operational challenges of electronic radiology. The well-known challenges include storing and managing the large quantities of digital data, the required quality of soft-copy display for primary interpretation and the responsive delivery of both images and associated medical information. This paper will focus on system bandwidth issues and technology limits related to achieving a responsive environment.

One of the initial objectives of our approach was to tightly integrate the existing radiology information system (RIS) into the processes of image acquisition, image storage and information retrieval. Transaction-based communication with the RIS

is used to validate image data sets prior to database insertion. The basic architecture of our Radiology Image and Information Manager (RIM) testbed is described by Figure 1. For the purpose of this paper we choose to focus on our experiences with the acquisition, storage and display of digitized images produced by computed radiography (CR).

In order to examine the impact of system architecture and design decisions on image communication, we first look at the available technologies. Technology choices of networks, disks, processors and database software must be put in a system context to determine their influence on the image acquisition and display times. Bandwidths for disk and network implementations, both peak and observed performance rates, are plotted versus the time to transfer a message of length representing a single CR or panel of smaller images. Example transfer times for images of a fixed number of bits ($1024 \times 1024 \times 12$ bits and $2048 \times 2048 \times 12$ bits) as a function of a channel rate are easily estimated from Figure 2. Response times less than 1 or 2 seconds require effective bandwidths of greater than 10 Mb/s. Times of a fraction of a second are likely to be needed for rapid scanning of image sets by experienced users. Parallel transfer disks (drives with multiple heads supported by parallel R/W electronics) and semiconductor cache memories offer bandwidths which push the 2K image response time below one second.

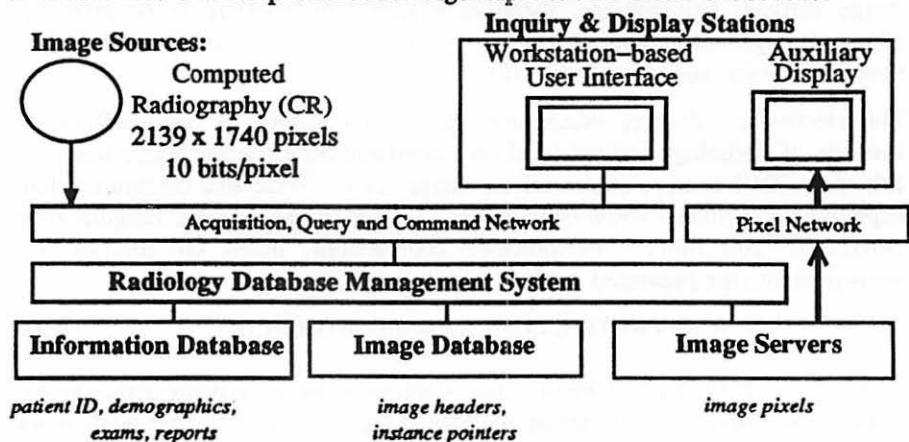


Figure 1. The Radiology Image and Information Manager (RIM) testbed developed at the Mallinckrodt Institute of Radiology coordinates acquisition of image data with the on-line radiology information system or RIS (shown as the Information Database), processes and stores the relevant image information (Image Database) and caches the image pixels on image servers. The Inquiry & Display stations support user queries to the RIM databases and display requests to the Image servers.

Responsive transfer times for image display (order of 1 second) can only be achieved for the narrow-band Integrated Services Digital Network (N-ISDN) and T1 channels using lossy-compressed image data and decompression hardware.

Ethernet is marginally adequate for image transfer during acquisition (detailed discussion in later section) but falls short for 2K display applications. Architectures using FDDI will likely require multiple rings to partition display load. Asynchronous Transfer Mode (ATM) technology, being standardized by the telecommunications industry, offers multiple channels at 155 Mb/s, and the high-speed fiber ring UltraNet has been deployed at several institutions and trials.

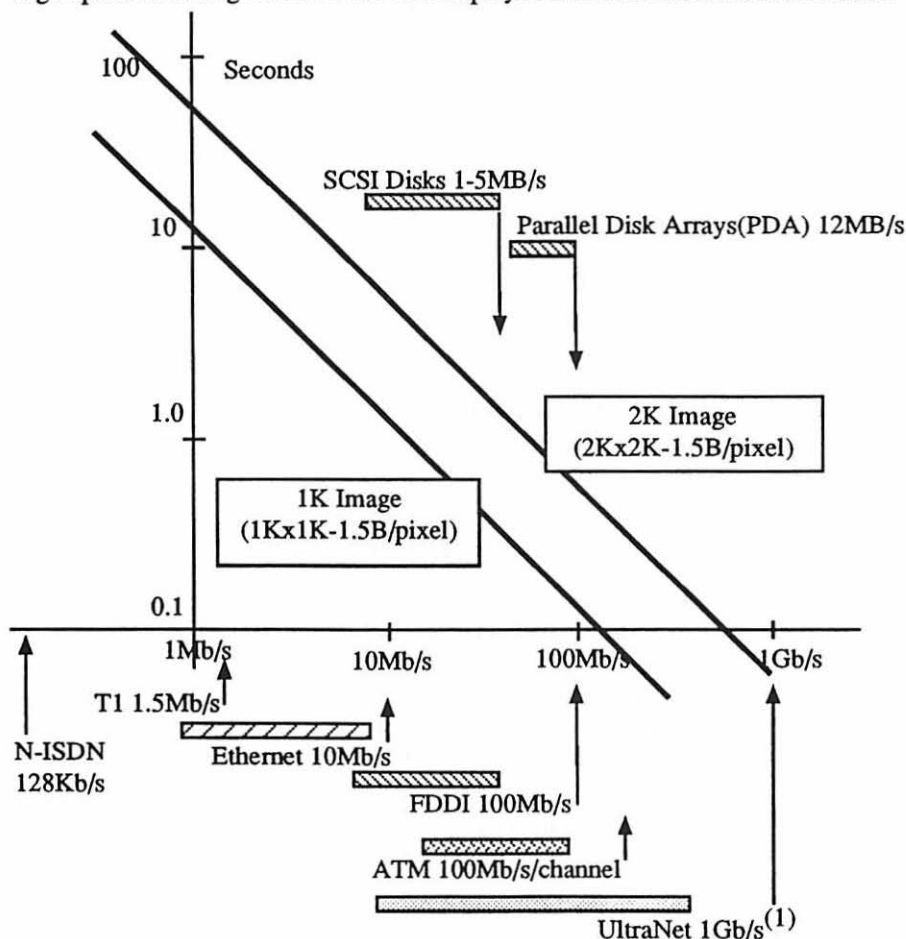
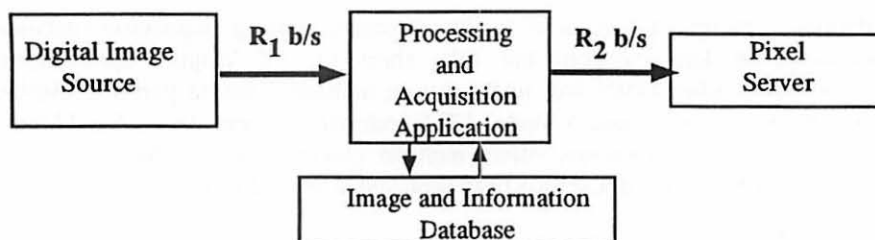
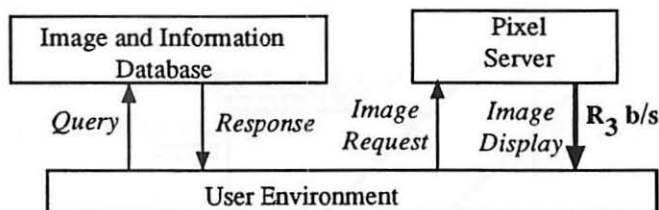


Figure 2. Image transfer time versus channel bandwidth shown for several network and disk technologies. The shaded bars represent actual performance observations.

Simplified models of the acquisition and display processes are shown in Figure 3. The channel rates, R_i , may be viewed as aggregates of the disk-to-memory and the memory-to-network-to-memory transfer rates. Each of the simplified models are discussed in the context of the RIM testbed in the following sections.



(a.) *Image Acquisition Model*



(b.) *Image Inquiry & Display Model*

Figure 3. Image communication model. The channel rates R_1 , R_2 and R_3 in bits per second (b/s) are labeled on the paths which support the transfer of image pixels. The message lengths of query and response transactions are small compared to the image messages.

ACQUISITION AND STORAGE PROCESS

We use the term "acquisition" to describe the process of capturing a digital image from an instrument and making that image available for display. Some implementations include an archiving step as part of acquisition, but we have chosen to implement archiving as a background procedure. The steps to acquire a CR image into the RIM system are: 1) Copy image header and pixel data from instrument into temporary disk storage of capture computer. 2) Verify image header (patient ID) against RIS. 3) Process pixels to enhance image (e.g., unsharp mask algorithm). 4) Format image for specific display technology (e.g., downsize). 5) Export image(s) to fast pixel servers.

As the digital image is captured from the instrument, it is copied to a local disk; when time permits, the file is copied from the local disk to a set of disks controlled by a VAXcluster. The disk to disk transfer time for the 7.4 MB file is approximately 75 seconds for an effective transfer rate of 800 Kb/s (R_1). Since the CR instrument is not tightly coupled with the RIS, we verify each header against the RIS to determine if the patient ID is correct and to determine if the image is to be acquired. The verification time is dominated by application setup and is currently on the order of 50 seconds.

After a CR image has been verified, four separate versions of the image are sent to a high speed pixel server for rapid display on soft copy devices. An edge en-

hanced version (unsharp mask) is computed, and both original and enhanced versions are cropped to 2K boundaries and sent to the pixel server. The 2K images are pixel-averaged at the acquisition node and the resulting 1K images are also sent to the pixel server. The duplicate images at different resolutions are precomputed to accommodate rapid display on soft copy devices with either 1K or 2K resolution. The elapsed time to compute the four image copies and perform other management tasks is approximately 8 minutes. The transfer rate from memory of the acquisition node over Ethernet to the disk of the image server is 1.6 Mbps (R_2). At this rate, the 18 MB of pixel information generated from one image is transmitted to the image server in 90 seconds.

Two metrics of interest for the acquisition system are the drop time for a single image and the throughput rate for a number of images. The drop time is the time that elapses from placing the plate in the instrument until the image is ready to be viewed. In the case of an idle Philips PCR 901, the drop time for one piece of film is about 3.5 minutes. The time to scan the plate and place the pixel data on the local disk is 75 seconds, so the drop time for the RIM system for one image is on the order of 13 minutes. Many of our testbed experiments have focused on capturing images from a limited number of intensive care units (ICUs). While one ICU may generate only 25 images in a day, many of the exams (15-18 plates) are done during one trip to the ICU and placed in the CR scanner at the same time. The PCR 901 will pipeline operations and can print a film every 68 seconds after startup. Some pipelining is performed by the RIM system so that its throughput is one CR image every 10 minutes.

INQUIRY AND DISPLAY

The Inquiry and Display model shown in Figure 3b incorporates database activity and image transfer times. One measure of responsiveness is obtained by calculating the elapsed time between the time of selection of a particular patient, t_{sel} , and the display of the associated image or image set, t_{disp} , as is shown in Figure 4.

When the radiologist selects a patient from the list of current examinations, the RIS is queried for a patient key (t_1). Next, the Images database is queried for image information (t_2), a pointer to the image pixels (t_3) and tonescaling parameters which are used to calculate a lookup table (LUT) for display correction (t_4). Finally, the pixel pointer and display command are sent to the image server, and the image is displayed on the auxiliary display (t_5).

Time t_1 measures the response time of the RIS and network link. Previous studies have shown this value to be 0.18 sec.⁵ Significant performance gains have been noted following a migration of the RIS to a more powerful platform, with response time dropping to less than 0.1 sec.

Times t_2 and t_3 measure the performance of the Images database, which is currently implemented with the VAX Rdb database management system (DBMS).

Response time of the Images database through the RIM application programming interface (API) averages 0.40 sec. for a typical transaction. Transitioning from a dynamic SQL-based API to one based on precompiled, embedded SQL promises to reduce these times. Table 1 shows some typical results obtained with precompiled or embedded SQL and various DBMSs for read-only SELECT transactions using an 80,000 record database of 500 byte Image records. Time t_4 , 1.20 sec., also includes the cost of calculating the LUT (0.80 sec.) from the tonescale parameters.

Time t_5 measures the responsiveness of the image server and the image communications link. After receiving a display request, pixel pointer and tonescale LUT the image server retrieves the pixels from disk, loads the LUT and sends the image to the auxiliary display. The pixel server requires 1.3 sec. to display a 4 Mpixel image to an embedded frame buffer.

The current implementation of RIM supports average response times ($t_{disp}-t_{sel}$) of 3.5 seconds. Sequential access of image sets allows a degree of pipelining to achieve the target response time of 2 seconds or less.

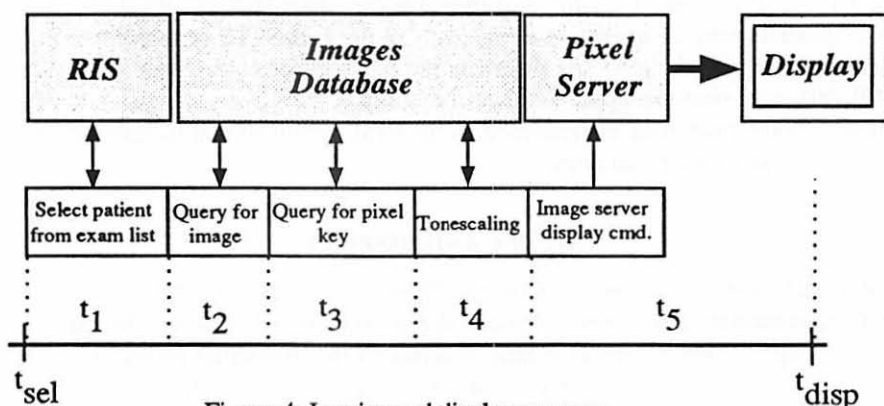


Figure 4: Inquiry and display process

Table 1: Observed SELECT response time, 500 byte records

DBMS	Platform	Operating System	Typical SELECT Response Time
Oracle	VAX 6220	VMS V5.5	0.24 sec.
VAX Rdb	VAX 6220	VMS V5.5	0.13 sec.
Sybase	Sun 4/470	SunOS V4.1.2	0.11 sec.

DISCUSSION

Primary interpretation of digitized projection radiographs on soft-copy display requires large pixel arrays (generally $2K^2$ or greater) delivered at responsive rates. Network technologies (including physical channel bandwidth and computer I/O constraints) are becoming readily available from both local-area (FDDI, ATM) and wide-area (ATM, SONET) distribution. Image storage technologies (magnetic disks, disk controllers, and computer channels) support rates of greater than 6MB/s, at storage costs on the order of \$6K/Gbyte. New introductions promise to halve the cost/Gbyte while maintaining the minimum transfer rates, or to offer devices with an order of magnitude increase in transfer rates.

Existing DBMS products, using precompiled embedded SQL queries, can be used to achieve random access and display capability in times on the order of 2 seconds. Image acquisition and storage processes may require priority scheduling or parallel processing architectures to minimize delay-to-view times during peak image generation intervals.

ACKNOWLEDGMENTS

The authors wish to acknowledge support of Southwestern Bell Technology Resources Inc., Eastman Kodak Health Sciences Division, Philips Medical Systems, Imlogix and Digital Equipment Corp. Many of our colleagues at MIR and Washington University's Applied Research Laboratory have contributed to our testbed project. Special thanks to Greg Brooks, Pediatrics and Keith Marrs and Paul Schoening, Medical Informatics for their assistance in developing the DBMS benchmarks. Finally we wish to thank Dr. Ronald Evens for his sustained support.

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TELEMED

The Largest European Project in Teleradiology

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Introduction

The **TELEMED R1086** project, being partially funded under the **RACE** European Community cooperative programme (R&D for Advance Communications in Europe), has been working on an extensive broadband communication network between widely dispersed medical experts and medical data resources within Europe since 1989.

Eighteen contractors and eighteen subcontractors from France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom under the direction of prime contractor DETECON (Deutsche Telepost Consulting Ltd., Germany) are participating in the **TELEMED** project. The choice of the project partners (physicians - in particular radiologists and cardiologists-, psychiatrists, medical equipment manufacturers, computer scientists, telecommunications engineers, network operators) guarantees that the **TELEMED** application pilots, mainly specified by users in clinics and special medical centres, are successfully implemented using state-of-the-art technology.

The overall objective of the **TELEMED** Project is the **Cooperative Diagnosis and Therapy in Medicine**, and, in particular, in **Radiology**, when participating physicians and psychiatrists can communicate over broadband communication networks.

Application pilots in the following areas have been installed:

- I. Remote Expert Consultation in Radiology using standard videoconferencing equipment**
- II. Remote Expert Consultation in Radiology by digital image transmission and on-line, synchronized image manipulation on workstations (including multivendor PACS-PACS communication)**
- III. Medical Codification and Radiological Image Reference Data Bases for use in care and teaching**
- IV. Patient Data and Images in Cardiology including cine transmission and remote quality assurance of modalities, Remote neuroradiological diagnoses by on-line transmission of MRI images, and Exchange of laboratory results,**
- V. Usage of desktop videoconferencing equipment in Mental Health Care and Teaching.**

Data protection and confidentiality form an essential part of the working programme. A working group exclusively deals with these problems and has worked out recommendations for users.

Modern broadband communication techniques are applied in order to improve the communication between medical specialists using audio and video transmission as well as fast exchange of high quality medical images.

Videoconferencing Techniques in Radiology

The first phase of Remote Expert Consultation aims at the technical and functional integration of standard videoconferencing equipment and networks in radiology for the exchange of radiological images and at the evaluation of these new techniques.

The university hospitals of Berlin, Heidelberg, Geneva, Lund and Tromsø purchased their own equipment so that a variety of implementations evolved giving TELEMED the possibility to compare different technical solutions. The hospitals have set up international links (see Fig. 1) using 2 Mbps or 140 Mbps transmission lines of the broadband networks VBN (the German videoconferencing network), MEGACOM (the Swiss videoconferencing network) and MEGANET (the Swedish videoconferencing network) in self-dialing mode, or the EVS (European Videoconferencing Services) in reservation mode. In order to interconnect the 140 Mbps VBN network with the 2 Mbps networks MEGACOM and MEGANET with a self-dialing capability a special gateway was developed and implemented by the German Bundespost Telekom and the Swiss PTT.

During the consultations conventional x-ray, CT, MR and DSA images were transmitted. The image quality was rated good over 140 Mbps and medium or good over 2 Mbps. A considerable enhancement was achieved by using the graphic mode on 2 Mbps connections although this is not necessary for every image. Consultations have covered so far interstitial lung diseases, cerebral lesions, liver lesions, Hirschsprung disease, Hodgkin disease, skull lesions, and vertebral trauma lesions.

It was observed that participating physicians require a minimum set of experience with the equipment and with the new working methodology in order to manage the consultation successfully. The images have to be presented by the requesting physician in a correct order so that the remote advising expert doctor can get an overview of the examination first. Then the expert may ask for special zooming-in with the document camera or for special images of the study. A second monitor with storage capability is considered essential to allow a comparison of images. For certain situations a cursor has been extremely useful. The self-dialing capability has proved to be an indispensable feature of the service as required by the medical users.

As a literature survey at the beginning of the project has revealed that no study existed about the diagnostic performance of teleradiology using standard videoconferencing equipment a ROC (Receiver Operating Characteristic) multipoint study was issued in order to get an objective assessment of image quality (besides the

already mentioned user experiences). For the ROC data collection the so-called rating method was adopted.

Fig.1: Communications trials for radiological image transmission by videoconferencing

Digital Image Exchange in Radiology

The second phase of Remote Expert Consultation aims at the technical and functional integration of medical workstations and PACS for the exchange of radiological images between university hospitals in different European countries (see Fig. 2) and at the evaluation of these new techniques.

Software has been developed on Macintosh II workstations for joint viewing and manipulation of images (OSIRIS viewing functionality, HERMES synchronisation software, and RECPHONE communications tool). Images stored in SIEMENS and PHILIPS modalities or PACS are transformed to the ACR-NEMA based public-domain image format PAPYRUS (agreed between all TELEMED partners) and exchanged using the TELEMED application programs.

The hospitals have set up international links using 2 Mbps transmission lines of the broadband networks VBN (the German videoconferencing network), MEGACOM (the Swiss videoconferencing network) and MEGANET (the Swedish videoconferencing network) in self-dialing mode, or 2 Mbps temporary reserved satellite lines. In order to interconnect the VBN network with the MEGACOM and MEGANET with a self-dialing capability a special gateway was developed, implemented and given into operation for TELEMED by the German Bundespost Telekom and the Swiss PTT.

The realisation of pilot trials is accompanied by the evaluation of the cost-benefit relation in the various phases, a specification of organisational, functional and technical requirements of future routine applications, the evaluation of the usability and potential for an extension of the application, an identification of medical areas (other than the pilot areas).

Fig. 2: Communications trials for Digital Image Exchange in Remote Expert Consultation

Medical Codification and Radiological Image Reference Data Bases

The third application scenario of TELEMED is based on the development and implementation of two radiological reference image data bases for scientific purposes and teaching, for the support of local diagnosis and therapy and for the support of the doctors' daily work. Existing medical classifications (ACR, ICD, SNOMED) were tested and supplemented by a classification of pathological image signs.

In order to make use of the expertise of medical centres, it was determined to set up one reference image data base for mammographies in Montpellier (France) as well as one for chest diseases in Florence (Italy). Cases of medical interest have been selected by doctors, commented on and stored in a data base. Medical staff at the Universities of Heidelberg (Germany) and Barcelona (Spain) will obtain access to the data bases and can retrieve the stored reference cases (Fig. 3).

The data base design being a combination of two data bases is closely linked to communications aspects. The data volume of retrieved images to be transmitted will be extensive and makes, therefore, high demands on the broadband communications links. The links to Florence are established by 2 Mbps satellite connections, whereas the link between Heidelberg and Montpellier is based on the use of all B-channels of three basic ISDN lines.

The development of a user friendly graphical user interface for the commenting of and access to the data volumes using medical terminology have played an important role. The workstations accessing the data bases run with the OS/2 and the UNIX operating systems and are able to load a data base, to comment on the images, to retrieve images, and to process images (inversion, zooming, control of gray scales, centres, width, distance and angle measurements).

Fig. 3: Communications trials for Image Reference Data Base Consultation

Multipurpose Exchange of Patient Data and Images

The German Heart Center in Berlin, the Patras University (Greece) and the Leiden University (Netherlands) deal with the possibility to synergetically use data of different modalities. Images of Thallium-CT heart muscle functional examinations as well as of heart-catheter-QCA anatomical examinations (including the presentation of the coronary artery tree) are exchanged using 2 Mbps lines of the networks VBN and MEGASWITCH or of satellites. The requirements on uniform image representation and communications for the assistance of medical image processing were worked out. An appropriate communications model using open standards and the OSI reference model was developed as a conceptual basis for the development of services which fulfill the communications needs of the international medical community (see Fig. 4).

The Leeds University (UK) has been developing testing methods for image generating medical modalities. Standardised test objects (phantoms) are used in Berlin on PHILIPS DCI's and the generated images are processed by means of specialised software tools in Leeds. This TELEMED pilot aims on the support of technicians and on the uniform adjustment of medical units so that a comparison of images becomes possible, even if they have been generated in various hospitals.

Communications requirements of remote users of clinical facilities to the required services and the needed technology for the installation of these services are examined. By means of evolutionary series of prototypes the transmission of clinical laboratory test results (and interpretations) from hospitals to general practitioners is currently tested in Dublin (Ireland) using X.400 technology.

NMR images are transmitted in Oxford (UK) between a hospital owing an GE MRI scanner to radiologists and neurosurgeons in another hospital for on-line remote diagnosis while the patient is examined. The demonstrator currently running on an ISDN basic rate connection will be operated over a 2 Mbps line.

Fig. 4: Communications trials for the Exchange of Patient Data and Images

Videoconferencing in Mental Health Care and Teaching.

The major objective of this application scenario is to improve communications between professionals in mental health care by utilizing broadband technology and computer-based desktop videotelephony.

Video communication systems based on PCs were designed and developed in TELEMED offering videotelephony with a resolution of 128 by 128 pixels, 64 gray scales at 25 frames/sec using 2 Mbps communication networks as the MEGASTREAM network in the United Kingdom. An integration of the video in one window of the computer screen has been carried out.

The systems have been introduced in mental health care settings at Guy's Hospital and at Speedwell Hospital in London and at Centre Hospitalier Spécialisé de Ville Evrard in Paris. In the clinical settings scenarios of interaction between different users have been analysed: psychiatrists talking to patients; senior doctors talking to junior doctors; doctors talking to nurses; doctors talking to medical students. Doctors ascribed greater distress to the patients using the link than the patients themselves reported. Doctors reported a high level of acceptance for using the link to talk to other doctors. Users who experienced discomfort on the telephone in daily life appeared to have negative attitudes to the use of the systems.

The participating psychologists have further developed and will apply during this year methodologies for the evaluation of the longterm use of the equipment in clinical

care, mental health nursing and in multi-national mental health teaching between London and Paris.

Conclusion

The results collected so far from the TELEMED application scenarios, which make use of state-of-the-art technologies in computers, broadband communications equipment and medical diagnostics, demonstrate the suitability of the implementations to meet the requirements of the medical applications defined. The experiments will continue until the end of 1992 and are accompanied by studies on user acceptance, cost-benefit analysis and legal aspects. TELEMED is contributing significantly in the definition of medical teleservices in the future Integrated Broadband Communications Network (IBCN) in Europe.

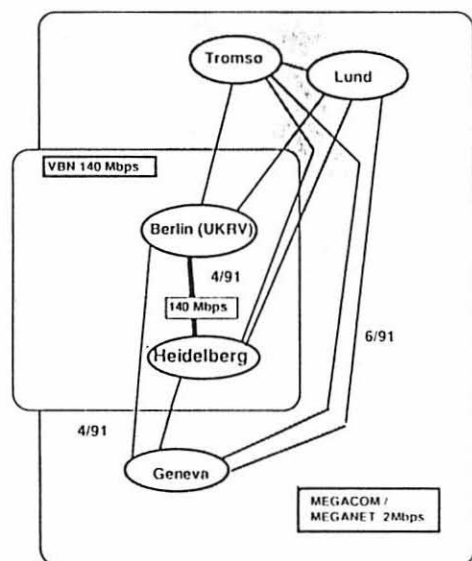


Fig. 1

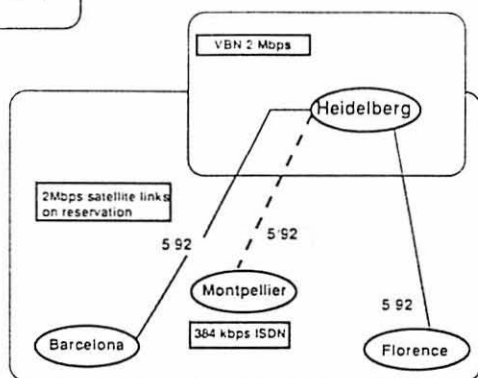


Fig. 3

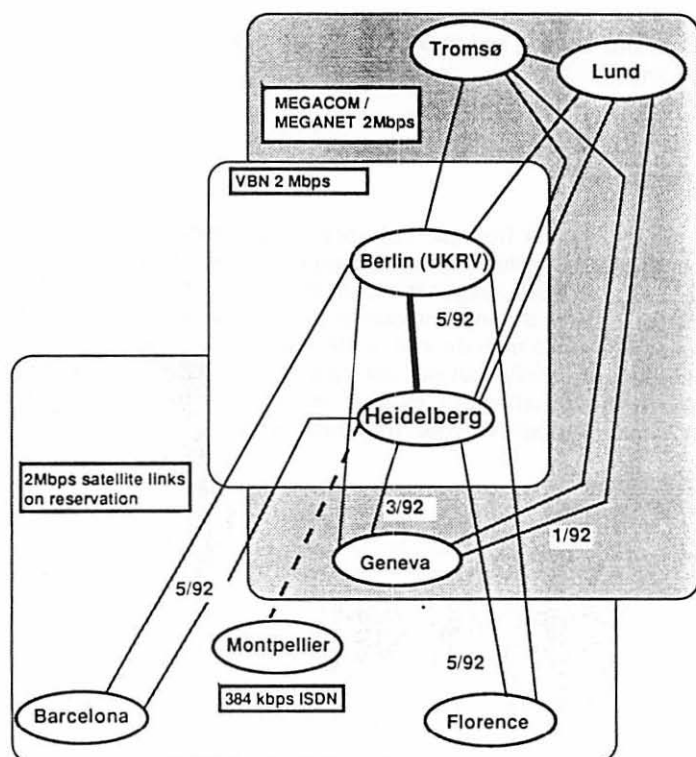


Fig. 2

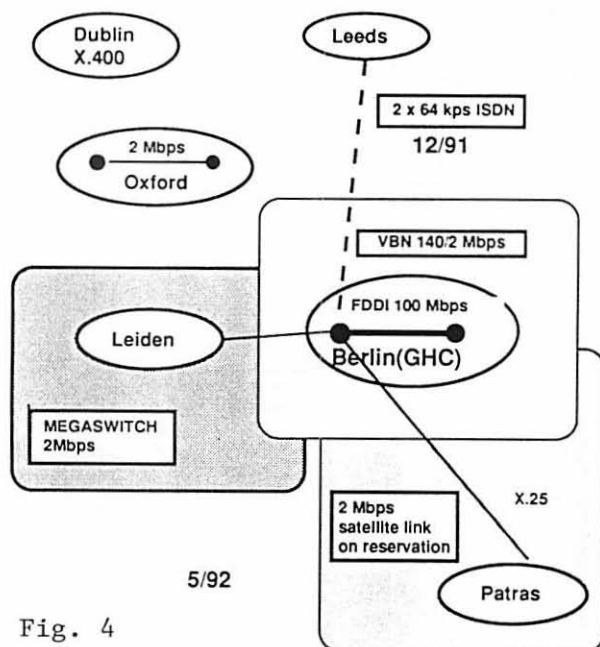


Fig. 4

Teleradiology of Direct Digital Dental Images for Consultations and Treatment Prior Approval

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University of Louisville Health Sciences Center, Louisville, KY

Two relatively recent advances are likely to make the teletransmission of dental radiographs a practical proposition not only for research institutions, but also for the general dentist working in a private office situation. These advances are: (1) the availability of direct digital systems for dental radiography based upon charged-coupled device technology (e.g. RadioVisioGraphy - Trophy Radiologie, Vincennes, France) with FDA approval; and (2) the growing availability of relatively wideband switched-digital telephone lines and of electronic mail networks.

Why should dentists wish to transmit radiographs and other clinical data via telephone lines? The first consideration is that of expedited referral for a second opinion, especially if the practitioner is located in a remote region where the patient would need to travel many miles to visit a specialist. More than 28 million persons in the USA live in underserved health-service communities in rural areas (1). Specialist consultation can be partly restored by the development of efficient telecommunication patient-data links to main centers (2).

A second reason for transmitting dental radiographs from private dental offices is the high proportion of cases in which prior approval from third party insurance carriers requires submission of radiographs (3). Radiographs are also often needed as proof of treatment rendered

prior to reimbursement by the insurance carrier.

Other reasons for transmitting dental radiographs include educational purposes (4) and use in forensic odontology. As the teeth are highly resistant to destruction, they are not infrequently used to identify human remains.

For these reasons it was decided to investigate the feasibility of the inexpensive transmission of dental radiographs both transcontinentally and intercontinentally using both switch-56 telephone lines (AT&T and US SPRINT) and electronic mail networks.

Materials and Methods

Images were acquired via direct digital CCD-based intraoral radiography. The source of radiation was a CCX dental X-ray unit (Trophy Radiologie, Vincennes, France) operating at 8mA and 70kVp. The receptor was a RadioVisioGraphy CCD X-ray camera (Trophy Radiologie, Vincennes, France). Images were stored in a standard PC-286 computer in Tagged Image File Format (TIFF). Each image represented an original surface area of 17x26mm and following 4:1 compression took 32kbyte of memory.

Switch-56 transmission was achieved both transcontinentally (5,6) and intercontinentally (7). Received images were both stored and retransmitted to the originator unaltered, and following image enhancement or annotation.

The Internet, a worldwide collection of thousands of interconnected computer networks which is used by approximately one million people daily, was the primary means selected for the electronic mail transmission of dental images both transcontinentally and intercontinentally. The NSFNET/Internet has a T3 backbone, with T1 connections between major sites. BITNET was also used for sites not connected to the Internet.

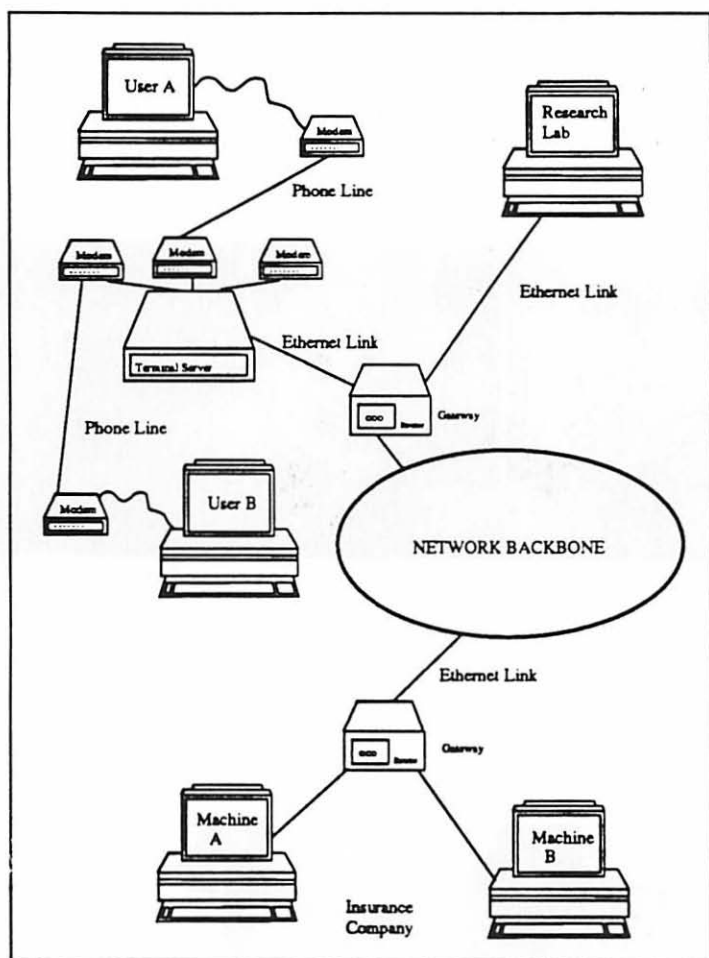


Fig.1: The electronic mail link.

Images were analyzed using digital subtraction and histogram analysis to determine the integrity of the received information. Manipulated images were restored using histogram equalization so that only changes such as annotations remained.

Results

Image Quality: Digital subtraction of unaltered transmitted images showed no loss of image detail (Fig.2) for radiographs transmitted both with switch-56 and through successful linkage using electronic mail.

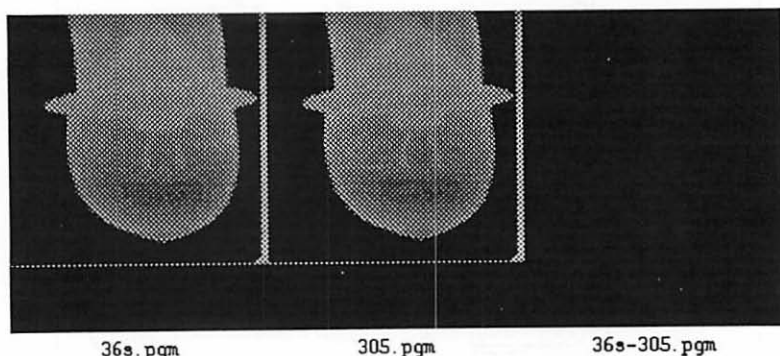


Fig.2: Transmitted image of light bulb.
Subtraction showed no loss of detail.

Following image manipulation subtraction revealed the changes that had been made (Fig.3) by the recipient prior to retransmission.

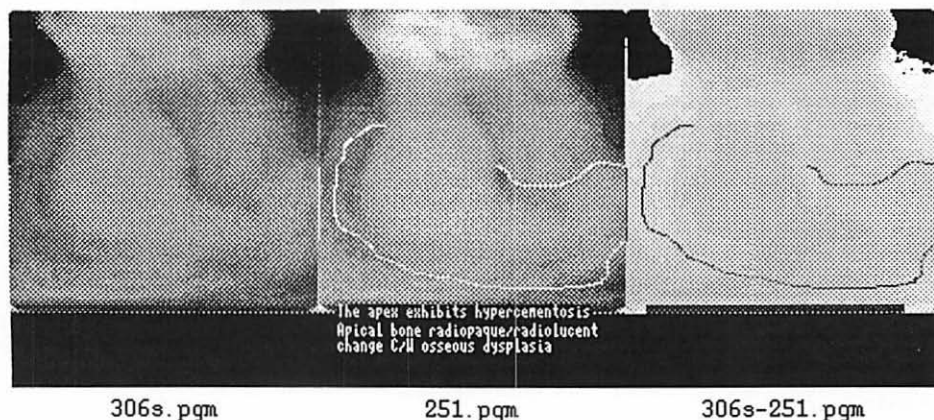


Fig.3: Transmitted image was manipulated by recipient before retransmission. The changes are obvious after digital subtraction.

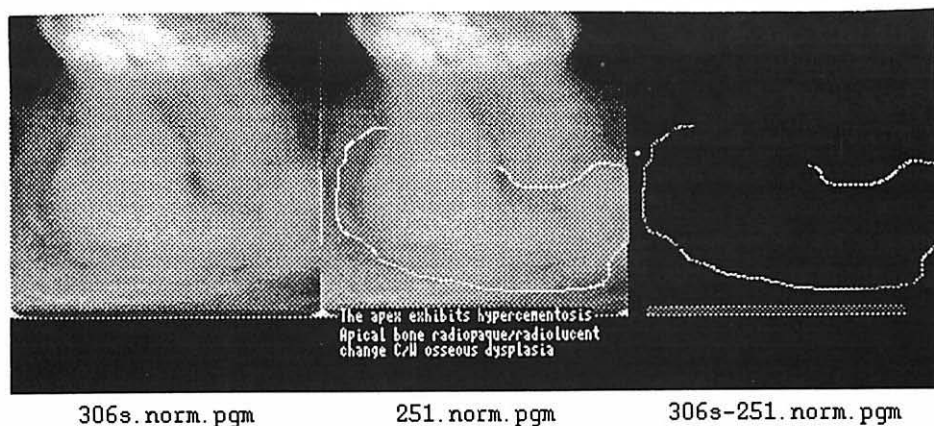


Fig.4: Following histogram equalization only the annotations of the recipient are seen on the image.

Histogram equalization of this case left only the recipients annotation on the image (Fig.4).

Transmission rate: Switch-56 allowed relay times of 4.6s for each image. The transmission time using electronic mail networks depended upon the amount of traffic on the line. Image reconstruction following receipt using switch-56 was almost instantaneous, whereas reconstruction of images received via electronic mail could take several minutes to perform depending upon the host and destination platforms.

Discussion

Whereas switch-56 works quickly, both the transmitter and recipient need to be online. Electronic mail transfer allows the recipient to open the mail at any time after the mail has reached the local node; however, the time taken in image reconstruction reduces the advantage of this convenience.

Concerning cost, switch-56 is still relatively expensive for the average dental practitioner. Electronic mail services are available in most locations in the USA for a modest monthly fee

(e.g. Performance Systems International, Inc., Reston, Virginia).

A further issue is that of confidentiality (8). While this is perhaps less a burning issue for dental radiographs than for medical records, the need for encryption of a patient's personal details should not be overlooked. The consideration here is no different than for radiographic original films or duplicate films currently submitted to third party insurance carriers.

Conclusions

It is now possible to transmit dental direct digital radiographs without loss of information, and at reasonable cost or speed depending on the urgency of the referral. More work needs to be carried out to improve the convenience of the translation softwares for electronic mail receipt of dental radiographs. Teleradiology has the potential of expediting second opinions and the interactions between the dentist and insurance companies.

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SESSION 7

**Computed Radiography
and Image Displays**

Chair: Robert Hindel

Comparative Tests of Two Storage Phosphor Plate Imaging Systems: the AGFA ADC and the FUJI AC-1+

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An Agfa ADC phosphor storage plate imaging system prototype has been undergoing clinical tests in the Georgetown University Department of Radiology since November, 1990. A Fuji AC-1 (recently upgraded to AC-1+) has been in clinical operation at Georgetown since September, 1990. Both systems have proved themselves by providing high quality bedside examination clinical images of the adult chest and are used routinely for this purpose. In addition, the AGFA ADC system is currently used routinely and interchangeably with conventional film-screen radiography (FR) for bedside and in-department chest radiographs in adults, for in-department studies of the spine, pelvis and extremities and for emergency abdominal examinations. With this use pattern, phosphor plate imaging has resulting a high degree of acceptance by clinicians and radiologists. The two systems in their current configuration each have specific advantages and disadvantages. The remainder of this presentation will discuss these differences.

SR AND CLINICAL DIAGNOSIS:

The AC-1 and the ADC produce images of the chest that, although they differ in appearance, appear to have similar diagnostic content. The AGFA ADC in addition has special processing (called Checkers processing) that results in images that appear as though they may contain additional information of interstitial lung disease compared to FR images. Tests are currently underway to determine if that is true.

Physician acceptance of images:

CHEST IMAGES: Both the AGFA ADC and the Fuji AC-1 images have been well accepted by the clinicians and radiologists. Because of the different appearance of the storage phosphor (SR) images compared to conventional FR images, the person viewing the images knows which images are which. For bedside examinations, the general opinion is that both the AC-1 and the ADC images are generally acceptable and are superior to FR bedside images obtained close to the same time. The acceptability of these images is based on the greater consistency of image radiodensity seen with these systems allowing easier comparison of images for the detection of minor degrees of change in disease severity. A test of image density consistency comparing the minimum and maximum optical density of FR, AC-1 and ADC is shown in TABLE 1. This demonstrates that the SR systems result in lower variability of optical density than FR and that the ADC provides better control than the AC-1.

Table 1: Optical Density of 16 bedside examinations, Minimal and Maximal Optical Densities:

Film-Screen:	Max O.D.: 2.43, S.D. 0.31; Min O.D. 0.90, S.D. 0.28
Fuji AC-1:	Max O.D.: 1.36, S.D. 0.25 Min O.D. 0.41, S.D. 0.10
AGFA ADC:	Max O.D.: 1.44, S.D. 0.13; Min O.D. 0.33 S.D. 0.05

BONE IMAGES: At Georgetown, the only SR unit used for bone image is the Agfa ADC. While we are still working to improve our algorithms for processing these images, it appears that these images will be better than conventional FR images for patients with osteoporotic bone. Tests of patients with subtle fractures comparing FR and ADC have so far demonstrated a slight advantage in ease of visualizing these fractures on the ADC images processed with the special "Checkers" algorithm. Further tests are underway.

ABDOMINAL IMAGES: Both the AC-1 and the ADC imagers are used for producing non-contrast abdominal examinations. The abdominal examinations produced on each system are considered of high quality and are completely clinically acceptable.

NEONATAL CHEST AND ABDOMINAL IMAGES: Neonatal chest and abdominal images have been obtained on the ADC unit. The image quality for the abdominal examinations is considered acceptable. The chest images have both advantages and disadvantages compared to conventional film-screen radiography. The image radiodensity is better controlled with SR and with FR. The SR device allows semiautomatic masking of the collimated image placing a gray background around the image. The image resolution is however less than desired and makes diagnosis more difficult. Comparing good FR images to good SR images we would prefer the FR images. If the usual FR image were frequently under or over exposed, we might prefer the SR image. Based on our findings, we have encouraged Agfa to work to provide a higher resolution imaging plate for this purpose.

Technologist acceptance: The technologists have been highly satisfied with the general ease of operation of both machines and prefer using the machines for portable examinations because of the high quality of images that result. The technologists do have complaints related to the difficulties of entering data into the identification system for both units, because of the extensive reentry of data that is necessary for these systems that is not necessary when simple flash cards are used with film radiography. It is hoped that the manufacturers will improve the film labelling system for both units. The film labelling system of the ADC allows the entry of a comment line that is printed on the image. The AC-1 allows a comment line, but this is not printed on the image.

Image Size: The AC-1 prints images on an 10 x 14 inch film partially filling the film with one or two images (image size 9" x 11"). The ADC allows images to be printed life-size (14 x 17 inch) or reduced in size on an 11 x 14 film (image size 9 1/2" x 11 1/2"), with one or two images per sheet of film. An ROC study performed at Georgetown demonstrated that there was no significant difference between FR bedside examinations and ADC SR exams printed at 9 1/2" x 11 1/2" and 14 x 17 inch size (ROC areas for identification of lung and pleural disease: FR = 0.88, Large ADC = 0.91, small ADC = 0.89). There are several published reports of the AC-1 that demonstrate no apparent diagnostic difference between FR and AC-1 printed on a 2 on 1 format. Although not scientifically tested by us, there appears to be no difference in diagnostic content in GT images of sequential FR at 14 x 17 inches and AC-1 images printed as a single image at 9" x 11" size.

Our radiologists have been reluctant to intermix images of different sizes for sequential reading. They prefer to read a series of all 14 x 17 or all 10 x 14 films, rather than a mixed set. They do not express a preference between the two sizes. Because of this, we have used the AC-1 which only produces a small size image in specific clinical units (our MICU and CCU). The ADC has been used with images intermixed with both conventional FR throughout the department and (when printed as a small image) intermixed with AC-1 images.

Number of different processing algorithms on an image: Both the ADC and the AC-1 allow images with different processing algorithms to be presented on a single sheet of film. The AC-1 allows 2 images on an 10 x 14 inch sheet of film. The ADC allows either 2 images to be printed on an 11 x 14 inch sheet of film or 4 images to be printed on a 14 x 17 inch sheet of film. It has not yet been determined to our satisfaction whether there is added diagnostic information available to the radiologist from having two images optimized with different algorithms available for review rather than a single optimized image. This possibility has been tested in part at GT by comparing the ROC area of images viewed as FR, ADC printed on film and ADC viewed on a workstation (ROC areas for lung and pleural disease: FR= 0.88, SR on film = 0.91; SR on WS 0.88). Manipulation of the WS image window level and window width resulted in no greater diagnostic yield than did the FR or ADC images viewed with a single optimized image. The WS used did not, however, allow the testing of different degrees of edge enhancement. While it has been demonstrated (by Schaeffer) that some algorithms are better than others in the diagnosis of disease, it has not yet been shown that two or more different algorithms would result in more disease being detected.

SR and PACS: The AGFA ADC transmits its images directly to our PACS network through a Georgetown designed ACR-NEMA interface. We have routinely been able to recall these images to our workstation. Tests of reader performance on the workstation have demonstrated diagnostic accuracy not statistically different than FR and ADC viewed as a laser print on film (ROC areas of lung and pleural disease FR= 0.88; ADC= 0.91).

SR QUALITY CONTROL ISSUES:

Quality control of SR images on the AC-1 and ADC is different. Each system requires different methods to assure that image quality is optimal.

Effects of under and overexposure: One of the advantages of SR imaging is that the system accepts a wide range of exposure parameters and prints an image with an acceptable final optical density. It is this that makes the system especially desirable for bedside radiography. The AC-1 allows exposure increases up to 38 times a 400 speed exposure with no deterioration of image quality. There is a risk that this high amount of potential overexposure of the patient may, by accident, become real due to machine malfunction or technologist error. We are aware of an accidental 10X exposure occurring in our institution due to the technologist misreading the decimal point of the digital exposure display.

The AC-1 can also produce an image with a 50 % underexposure that (for the chest) is probably acceptable for the lungs, but appears to lose information in the mediastinum. It is difficult to determine from the image obtained whether the image contains full diagnostic information.

The ADC using a different method of image production allows for a 2-3 fold increase or decrease in exposure while still producing an image. In a reader performance test of an anthropomorphic phantom with simulated lung nodules, it was found that full information was present when 0.13 mR minimum exposure reached the imaging plate. (this was equivalent to a 400 speed system in the thickest part of the mediastinum.) Exposures of 1/2 of this resulted in information loss even though the image appeared acceptable.

Collimation: Because of difference in the method used to produce an image, the AC-1 and the ADC respond differently to collimation. The AC-1 includes a collimation choice switch that adjusts the area of exposure estimation to the region collimated. If the technologist fails to correctly select the pattern of collimation used, the final image optimal density is increased. On the ADC, the collimation adjustment is automated and the technologist does not need to indicate that collimation has taken place.

Body part does not fill area of image plate: If the body part radiographed does not fill the image plate and the technologist fails to indicate on the AC-1 control plate that only a part of the image should be used as the basis for the image density, the image will come out light. This problem does not occur with the ADC.

Reprocessing of poor images and duplicating images: Both the ADC and the AC-1 allow images to be reprocessed and/or duplicated by the use of a remote console. The systems are equally easy to use once the systems have been learned. For this task, the instruction manual for the ADC is easier to understand than that for the AC-1.

Finding a damaged or dirty phosphor plate: When initially installed we were told that we could not number the Fuji phosphor plates for identification purposes. Fuji now allows this numbering. Without this identification on the imaging plate it is very time consuming to identify the damaged or dirty phosphor plate in the Fuji machine since 10 plates are stored within the machine. The ADC stores within its database the cassette and phosphor plate number used to create each image. Dirty cassettes are therefore easily located by consulting the stored database.

QC of the imaging chain: The recommended QC procedures for the AC-1 and ADC system differ. The ADC system processes an image through the entire imaging chain from the plate to the plate reader, computer, laser camera and film processor to determine whether the image quality is correctly adjusted. A test phantom is being devised to improve this procedure. The computer can also generate an electronic "stepwedge" of densities to test the laser camera and film processor. The Fuji recommended QC image is produced by the computer and tests only the laser camera and the film processor.

SUMMARY:

Clinical comparisons of the Fuji AC-1+ and the Agfa ADC phosphor storage plate imaging systems demonstrate that both systems can produce high quality images of the chest at the bedside and for in-department exams of the abdomen. We have also used the ADC for in department chest radiographs, skeletal radiographs and, in newborns, portable radiographs of the chest and abdomen. We have limited the AC-1 SR device primarily to bedside chest radiographs in specific clinical units where it is used consistently. We are reluctant to intermix images of different sizes, and therefore have not used the AC-1 routinely within the department. The ADC, however, can produce lifesize examinations and we have freely intermixed these images with FR images. To us, the main advantage of the use of the ADC in the department is the ability to directly transmit the image to the PACs and also to reprint images when then cannot be retrieved from the file room.

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Digital Luminescence Radiography in Portable Chest Radiographs. A Comparison Between Digital Radiographs Reviewed on a Personal Computer and as Hardcopies

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Digital radiography seems today to be accepted as equal to conventional radiography using the film-screen combination^{1,2,3}. Because of that, much work is being performed to develop picture archiving and communication systems (PACS) in order to be able to benefit from the digitization. Accordingly, a possible development in the future radiology departments will be to review all examinations on monitors, and only exceptionally document the radiographic information on film.

In a former study using a chest phantom we have demonstrated that the performance of an interactive image-processing work-station (Digiscan, Siemens, Erlangen) was sufficient for diagnosis, at least for the test objects used⁴.

The aim of this study was to determine whether a personal computer (PC) is sufficient for routine diagnostic use as a preparation for placing this computer in the intensive care unit (ICU), with transmission of images from the department of radiology.

Methods and material.

Radiographic technique.

The portable chest radiographs in the wards were performed on a multi-pulse generator (Mobilett, Siemens, Germany) with a film focus distance of 120 cm using 90 kV and 10 mAs. The focus size was 0.8 mm. In the radiology department the examinations were performed with a 12 pulse generator, film focus distance 120 cm at 90 kV and 10 mAs. The focus size was 1.0 mm.

A digital system based on Fujis image plate technology was used (Digiscan, Siemens).

An interactive image-processing work-station (Digiscan, Siemens) containing a computer, an optical disk and two monitors, was connected to the main computer, making it possible to store the examinations for reprocess-

ing. The resolution of the image with a 35x43 cm image plate is 1760x2140x10 bit, which can be displayed at half the resolution at full size, or at full resolution using a detail function, but then only part of the image is shown.

The data are stored as raw data on the optical disk, i.e. without any processing, and the work-station does not have the same possibilities to filter and enhance these data the same way as the hard copies are processed when the original examination was done. We chose to transmit the 1000-pixel image to the PC, thus further testing if this lower resolution was enough for routine diagnostic use. The images were transferred to the PC (LiteBox™, Siemens), which is a PC-based diagnostic review workstation connected to a 1200x1024x8 bit grey scale monitor. It was configured as a modality work station for image review and interactive processing. System interaction is by use of a mouse, pull-down menus, windows and a key-board. Working at the PC, the observer could interactively change the contrast in the image, zoom different parts and move the image on the monitor.

The digital radiographs were printed with a laser printer on a single 26x36 cm film with a resolution of 2.5 linepairs/mm. Two images were produced from the same exposure, where one was simulating the conventional film-screen image, and the other was edge enhanced in order to amplify weak signals.

Patient study.

The material consisted of portable chest radiographs from 75 patients, 49 males and 26 females, 1-88 years (mean 58.9). Of these, 67 patients were examined in the ward using the supine a.p. projection and 8 patients supine at the radiology department. Three observers participated in the study where two were chest radiologists and one anesthesiologist working at the thoracic intensive care unit. Twenty-eight of the patients had had cardiac surgery, 12 patients had been operated in the lung, esophagus or aorta, 5 had been operated in the abdomen and 5 had had neurosurgery performed. The remaining 25 patients were not operated, but controlled for myocardial infarction, heart arrhythmias or renal insufficiency.

Phantom study.

The patient study was supplemented with 25 chest phantom radiographs from an ongoing study. In this study, different test objects simulating tumors are placed randomly on the back of the phantom, 3 in the mediastinum (6, 12 and 18 mm. respectively) and 1 in the right lung (6 mm). Because the study has just started, only the results from two of the participants could be obtained and only 25 of 100 examinations. Even here results from PC and film were compared.

Evaluation.

Patient study.

The three observers reviewed the 75 chest radiographs on the PC monitor and on digital radiographs independently of one another and at three different sessions with monitor and hardcopies respectively with about 25 images at the time. The observers had no knowledge of clinical data, which were collected after the viewing sessions from surgery reports and/or the reference chart for pulmonary radiography.

Eleven objects (Table), routinely checked by the ICU physician, were identified in each

	Artificial heart valves	12
	Atelectasis	55
	Carina	75
	Central venous catheters	38
	Chest tubes	30
Table.	Gastric tubes	30
	Myocardial electrodes	28
	Pleural effusion	32
	Pneumothorax	4
	Sternal sutures	26
	Tracheal tubes	25

patient and a protocol used with three possible answers for each object:

1) *Well seen* - the object should be identified as a whole, i.e. all six sutures in the sternum should be identified. This has a clinical relevance, since it is important to see that none of them are broken. The complete gastric tube should be seen, the whole of the chest tubes and so on.

2) *Poorly seen* - if part of the objects could not be properly identified this was reported.

3) If the object was *not seen at all*, this was reported.

After reviewing all 75 cases on monitor and digital radiographs all three observers met to obtain a consensus of what was seen in the different patients. For 8 of the 11 objects the correct answer was obvious from the surgical report mainly. Regarding pneumothorax absence or presence could be affirmed by reviewing previous and later radiographs. The correct answers for the remaining two objects, atelectasis and pleural effusion, were defined at the consensus. For each patient and each object, it was noted whether the observers had described the object as seen well, poorly or not

at all. This was compared with the correct answers as defined by the consensus.

Statistical method.

A correct answer from an observer is given the value zero i.e., when the object present is reported well seen or when an absent object is reported not seen. When an object is reported as poorly seen this was given the value 1 (irrespective of the correct answer), and an incorrect answer the value 2.

For each patient and object, the scores of the three observers were added for monitor and film respectively, giving a sum between zero (best) and six (worst) for each of the two techniques. Altogether the data give $[75(\text{patients}) \times 11(\text{objects})] = 825$ pairs of sums with which to compare the performance of monitor and film.

The statistical test used were the sign test and the Wilcoxon matched-pairs signed ranks test^{5,6}.

Results

Patient study.

We found practically no difference between the performance of monitor and film for the whole material. We have three viewers, 75 patients and 11 objects which gives a total of 2475 individual observations for monitor and film respectively. For monitor 92.3% of the observations were correct and for film 92.1%. The former had slightly more incorrect observations than the latter (5.4% versus 4.4%) but slightly fewer cases which were reported as poorly seen (2.3% vs. 3.5%). Neither the sign test nor a one-sided Wilcoxon test could demonstrate a significant difference between the monitor and hard copy sessions when used on the whole material. When looking on the individual objects, both viewing methods were equal in 9 objects, but a one-sided Wilcoxon test showed significantly better results for film for central venous catheters and myocardial electrodes.

Phantom-study:

The smallest test object (6 mm.) in the mediastinum was too small and was disregarded after a short time. The 18 mm. test object was too obvious as can be seen from the resulting ROC curves (Fig 1) and was also eliminated. The 12 mm. mediastinal and the 6 mm. pulmonary test objects seemed to be better as the resulting curves show (Fig 2). The difference between the curves evaluated with a paired T-test revealed no significant difference between diagnosis made on film compared to diagnosis on the

PC ($p < 0.05$) for both objects.

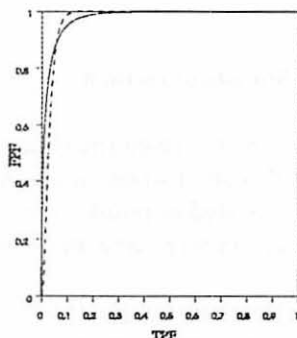


Fig 1. The difference between monitor and hard copies using the 18 mm test object. (—) hard copy, (----) monitor.

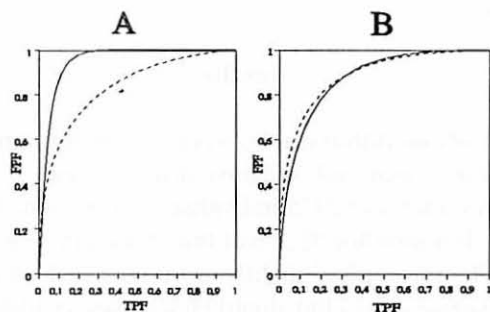


Fig 2. A is showing the performance using the 12 mm mediastinal test object, B the 6 mm pulmonary test object. (—) hard copy, (----) monitor.

Discussion.

It is possible to transfer an image at full resolution to the PC, but only the monitor image, e.g. an image with half the resolution, was transferred. The reason for this was 1) to see if this resolution was sufficient for the purpose 2) in order that a sufficient number of images - both the most recent and at least one previous examination - should have room on the hard disk, it was necessary to reduce the size of the images by choosing the lower resolution. The image was transmitted to the PC without any processing because we found this more realistic in real use; the radiologist cannot be expected to have the time necessary to do this, the image will be transferred as it is with the report included.

Obviously tests like these cannot prove the absence of a difference between the two viewing methods. Furthermore the power of the tests depend on the kind of difference which is hypothesized to exist (the power efficiency of the Wilcoxon test is about 95% of that of a T-test, assuming normality⁵). Nevertheless the statistical results suggests that there may be no major difference between the two techniques in terms of performance in a clinical setting.

The study was not intended as a performance study because of the participation of a non-radiologist, but the phantom study will be performed as a ROC analysis.

It might seem that the objects we have registered in our study are too easy for reliable statistic evaluation, but since they constitute the things of interest in routine work in the ICU we found it worth while to compare the two methods with regard to these objects. Furthermore, the preliminary results of the phantom study seems to confirm our results in the present study.

Our results suggests that there might be significant differences in the performance of monitor images and radiographs at the resolutions used, but only with respect to specific very small objects such as myocardial electrodes. Further work will establish whether such differences is of any significance.

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Ink Jet Technology for the Printing of Digital Radiographs

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I. INTRODUCTION

Although a total digitization of the radiology department has become technically possible with the introduction of digital projection radiography, radiologists usually prefer and are more accurate with hard copies than with monitors, and it is a widespread opinion that the former must be retained¹. Our result so far from evaluating a computed radiography (CR) system²⁻⁴ with a 1200 line monitor, using a chest phantom, indicates that for the morbidities studied, pulmonary and mediastinal tumors and pneumothorax, the resolution of the monitor is adequate for reliable diagnosis⁵. For this reason we think that the primary diagnosis even today probably can be made safely on a monitor. On the other hand, hard copies may be retained for other reasons, e.g. for demonstration where monitors are unavailable, but then a less expensive medium than today's photographic film would be preferred. Therefore we are evaluating paper copies printed with the continuous ink jet technique as a considerably less expensive expendable substitute for film^{6,7}.

In this paper the continuous ink jet printer is described. Further, samples of ink jet printed radiographs derived from a CR-system are presented. Our results, so far, show that the quality of the paper prints is slightly lower than that of a film print, of enhanced image data, from the CR-system. However, for demonstration purposes, the ink jet prints have a sufficient quality. With further development of the printing technique and an optimized processing of the image data, we think that the ink jet prints may reach a quality level sufficient also for diagnostic tasks.

II. METHODS

The ink jet printer is based on the Hertz' continuous ink jet method and has been developed at the Dept. of Electrical Measurements^{6,7}. Figure 1 shows the principle of generation and control of the ink jet. By forcing ink under high pressure through a 10 μ m diameter nozzle, a fine jet is generated having a velocity of appr. 60 m/sec. By stimulating the nozzle mechanically with a piezo-electric crystal, supplied with a 1 MHz-signal, the ink jet breaks up into separate and equally sized drops at a rate of one million drops per second.

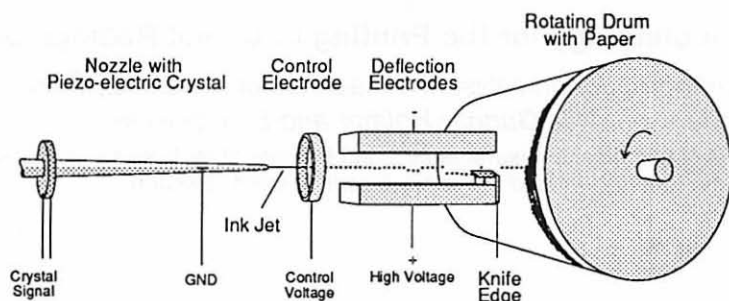


Fig 1. Generation and control of the continuous ink jet.

The ink jet is electrically on-off controlled by means of charging and deflection. At the point of drop formation a control electrode is located and to which the control voltage is applied. With a control voltage of +80 V negative charges will be attracted to the jet tip and the ink drops being formed will be negatively charged. With the control voltage connected to zero (ground potential), the drops will remain uncharged. Shortly beyond the control electrode, the drop train enters a static high voltage field, generated by 2000 V between the two deflection electrodes. Here the charged drops will be deflected towards the lower electrode and caught below a knife edge. The uncharged drops will continue, unaffected by the deflection field, and finally reach the recording paper which is attached to the fast rotating drum. Thus, by switching the control voltage at a maximum frequency equal to that of the drop formation, every separate drop can be controlled to either reach the paper or not.

Figure 2 shows the main parts of the ink jet printer. The nozzle and the electrode system are assembled in the printhead, situated in front of the paper bearing drum. As the drum rotates the printhead is slowly moved sideways by a stepping motor, one image line per revolution. Each pixel around the drum can be addressed by monitoring the drum position by a shaft encoder. The control voltage for the on-off switching of the ink jet is generated in the control logic unit, according to the image data which is entered from a Macintosh front-end computer ⁸.

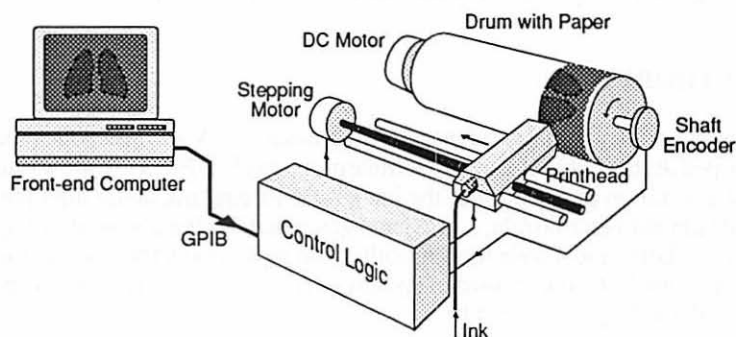


Fig 2. The main parts of the ink jet printer.

In order to generate different gray levels the true halftone technique is utilized, that is, the dot size in each single pixel can be varied. This is due to the small size of one separate drop. Figure 3 shows how the resulting dot size is varied according to the number of drops deposited in a pixel⁶. In the present printer 32 different gray levels (including white) can be generated in each pixel. Further, by combining these discrete levels over a small area with an error diffusion algorithm⁹, the number of reproducible gray levels has been extended to 256.

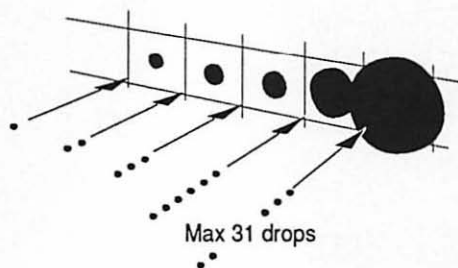


Fig 3. True halftone generation in the ink jet printer. The number of drops deposited in each pixel determines the dot size.

According to the above principles a one-color printer has been constructed for printing with a spatial resolution of 10 pixels/mm (5 Lp/mm). The drum dimensions have been chosen to match the size of the radiograph prints from the CR-system, 356 x 254 mm², and the time to print a full size image is approximately 4.5 minutes⁸.

Digital radiographs of patients as well as a chest phantom were selected for this printing experiment. All images were derived from a CR-system (Siemens Digiscan) via a μ Vax II host computer, at the Dept. of Diagnostic Radiology, to the Macintosh computer controlling the printer. The image matrices of 1760 x 2136 pixels were represented by 10 bits/pixel. The only way of extracting the image data from the CR-system was by recording the normalized raw data, i.e. coarsely level adjusted and non processed data. Therefore the image had to be further processed in order to reach the level of diagnostic quality which is delivered by the CR-system on photographic film². New window settings were performed by using commercial software, Adobe PhotoshopTM, together with a specially deduced format conversion software. The images were further edge enhanced by using an unsharp mask filter in the Adobe PhotoshopTM software. Since this software was able to handle images with only 8 bits/pixel (256 gray levels), the pixel values within the selected window width were converted from 10 to 8-bit-values before the filtering procedure.

III. RESULTS AND DISCUSSION

Figures 4 and 5 show digital radiographs from the CR-system printed by the ink jet printer on paper. The prints have matrices of 1800 x 1760 and 1760 x 2136 pixels, respectively, and are printed with a spatial resolution of 10 pixels/mm, which

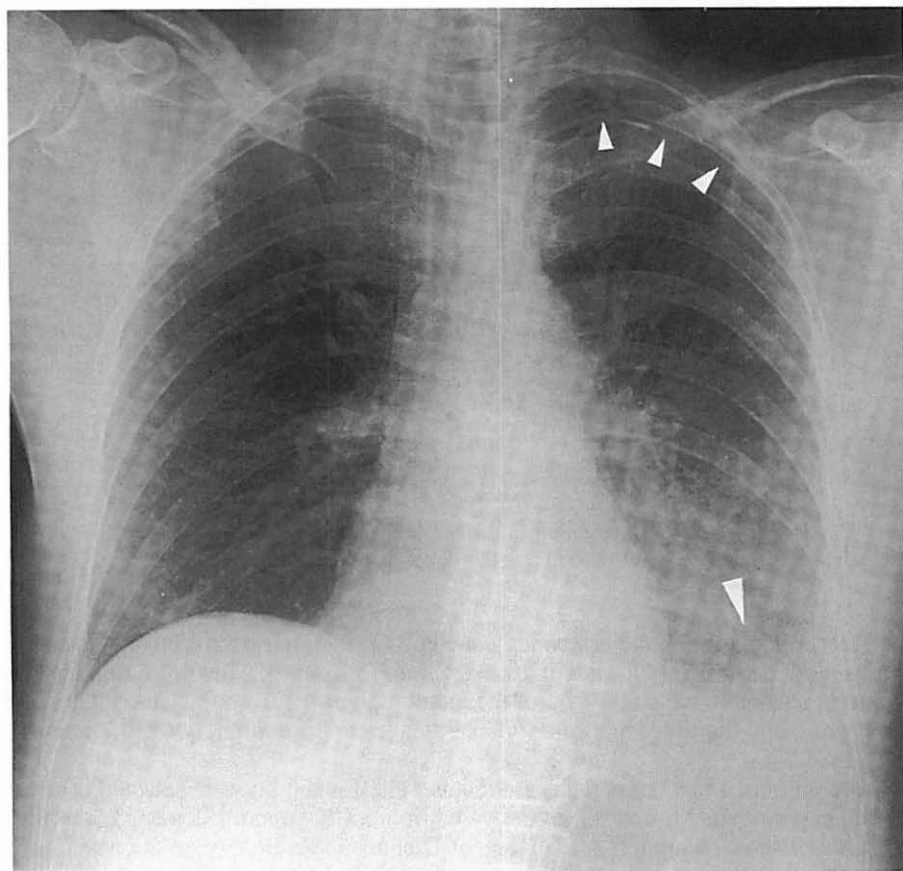


Fig 4. Ink jet printed radiograph on paper with a matrix of 1800 x 1760 pixels which gives a print size of 180 x 176 mm². The patient had a left apical pneumothorax and effusion in the left pleural cavity.

is the same resolution as used in the CR-system film recorder. The images were printed with 32 true halftone gray levels, which by use of the error diffusion algorithm were extended to 256 gray levels. The ink used was black "Mingograph writing fluid" supplied by Siemens-Elema AB (Solna, Sweden) and the print medium was a special ink jet paper, IJ Mattcoat NM, from Mitsubishi Papermills (Japan). This ink/paper combination gave a smooth and high densified print to be viewed with reflected light, i.e. as an ordinary photograph.

Our results show that the quality of the ink jet prints is slightly below that of comparable edge enhanced images recorded on film in the CR-system. However, all details of diagnostic value observed on the film prints were also visible on the paper prints. Further, it should be emphasized, as stated in the introduction, that our first

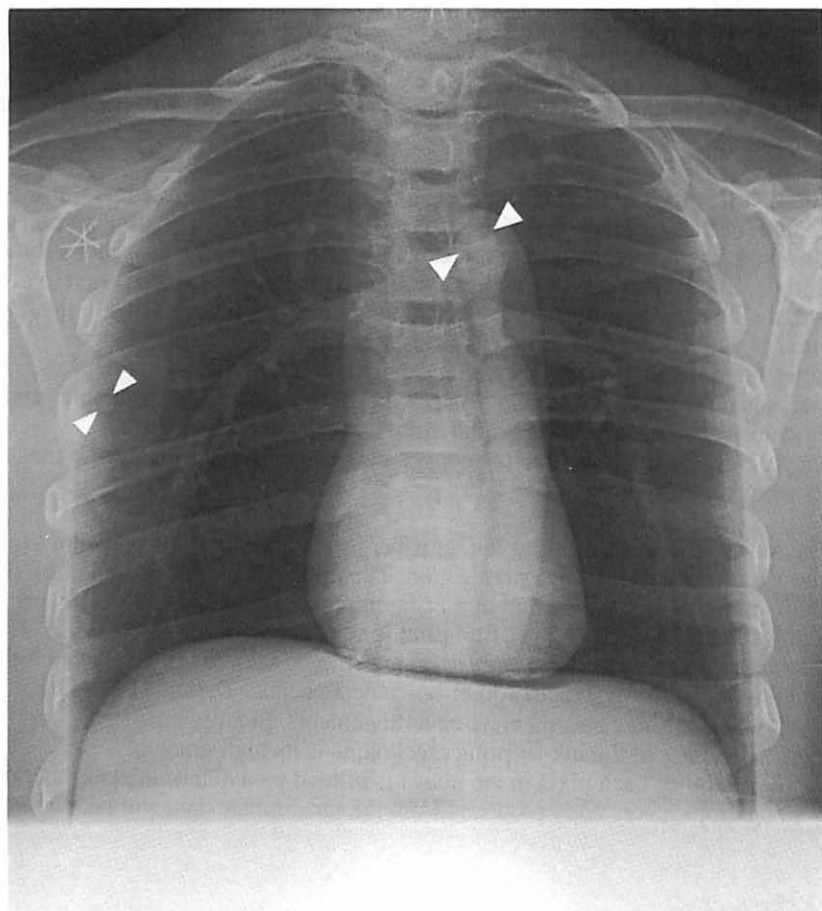


Fig 5. Ink jet printed chest phantom radiograph on paper with a matrix of 1760×2136 pixels which gives a print size of $176 \times 213.6 \text{ mm}^2$. Test objects (6 and 12 mm) were placed in the right lung and the mediastinum, respectively. The unmarked "tumors" were fixed structures.

intention is to use the paper copies not for diagnostic use, but for demonstration. The quality of the ink jet prints can be further improved by increasing the number of gray levels, particularly in the lower density region. Preliminary experiments with a combination of different inks have shown promising results. Further studies towards an optimal processing of the digital image data will also be of great importance for an improved print result.

As mentioned earlier, the time to print one image is around 4.5 minutes which is too long, compared to that of the CR-system film recorder and developer units which have a printing and developing time of totally 2.5 minutes². However, the time can be reduced by using a multi-nozzle printhead. Nilsson et al. have already presented a color ink jet printer using a four nozzle printhead for the primary colors cyan, magenta, yellow and black^{10,11}. By exchanging the different colored inks to only black ink the printing time can be reduced to around one minute which is even shorter than that of the CR-system.

The light fastness of the present ink/paper combination is limited. A thorough investigation of the long time stability has not yet been made. The fading procedure depends on the chemical structure of the paper and the ink, and the conditions for the print storage, like temperature, humidity and light. If the images are exposed to direct sun-light, the images show tendencies of fading after only a few weeks. On the other hand, images which have been stored in a closed drawer, at ordinary indoor conditions, have shown none or very little changes over a period of many years. However, since the paper prints are primarily meant to be used as expendable prints for momentary demonstrations, the fading problem should not be of great importance. Because the low price per copy, a new copy can be printed from the digitally stored data on demand.

The major advantage of using ink jet paper prints instead of today's film prints for demonstration tasks is the economic gain. The price per ink jet printed copy is more than ten times lower than that of a print on photographic film: 15 cents per paper copy compared to USD 2 per film print (prices in Sweden, March 1992). The fact that the radiographs are being printed on paper to be viewed with reflected light, brings additionally the advantage of light-box independence. The images can be viewed anywhere without special viewing arrangements. Finally, another advantageous feature of the ink jet printer technique is its high grade of reproducibility. Since each pixel in the image is printed by a determined number of equally sized drops, every copy produced from the same image data will be identical.

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ROC Studies Using the CRT and Computed Radiography

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I. Introduction

In the past, radiographic film has been used for image acquisition, archival, and display. However, developments beginning with the introduction of computed tomography have led to sonography, magnetic resonance imaging, and computed radiography (CR) where acquisition and display are separated and the modality is digital rather than analog. Each of these new modalities can use a display system with a cathode ray tube (CRT) for viewing anatomical images. Picture archiving and communication systems which link various digital radiographic imaging modalities electronically and teleradiology systems have further increased our need to use digital viewing stations. Conventional film may also be included in digital systems through the use of a laser digitizer. Hard copy of digital images is created by laser film cameras.

Questions about the efficacy of digital systems are especially intense when the comparison is made with conventional film (CF). This is true both for digitized film and for computed radiography. Both of the digital systems have significantly less spatial resolution than film. Consequently, many investigations have been directed at the comparison of film and digital images looking for the digital resolution which would give equivalent observer performance for the two.¹⁻⁸ The studies which we detail use receiver operating characteristic (ROC) analysis.⁹⁻¹⁰

II. Experiments

A. Digitized Radiographs

One hundred and sixty-three chest radiographs in nine disease categories were digitized ($2048^2 \times 12$ bits). The digitizer used a laser spot size of 0.08 mm. and the sampling frequency was 312 samples per inch, giving 4,096 samples across

its 35-cm. field. The images were reduced to 2048x2048 by pixel averaging. The images were presented to six readers as conventional films, laser printed digital films, and displayed on a high-resolution CRT (2560x2048).

B. Phosphor Plate Venography

Simultaneous half-exposure plate and full-exposure conventional films were obtained of thirty-five patients. The task was the detection of acute venous thrombosis. Eight observers were grouped according to their experience. Four had extensive experience in reading CR and four had limited experience in CR. All readers read all images in two sessions about one month apart. In each session each participant read randomly selected images of which one-half were CR and one-half were CF.

C. Musculoskeletal Phosphor Plate Radiography

In the second experiment, 140 cases involving musculoskeletal findings, fracture, soft tissue injury, tumor, and foreign bodies, had both CF and CR examinations. The conventional film studies were performed using standard exposure techniques. About one-third of the CR examinations were taken at 100% of the CF exposure. About one-third of the CR examinations were taken at 75% of the CF exposure and the remainder were done at 50% of the CF exposure. The majority of the diagnoses were fractures. The images were presented to seven readers in two sessions separated by about five weeks. In each session each participant read randomly selected images of which one-half were CR and one-half were CF.

III. Results

A. Digitized Radiographs

Significant differences in diagnostic accuracy were linked to changes in contrast in the digital images. Readers overcalled interstitial disease on the digital displays (Table 1) because of the increased contrast over the conventional film. Thus the conventional film performance was significantly better than the digital performance. However, on the detection of parenchymal mass, the digital film performance was significantly better than the conventional performance. In this task, the ability to increase contrast in the digital images helped the diagnosis. CRT performance was degraded in the detection of pneumothorax. This task is dependent on the recognition of a very fine line and thus requires good high

frequency performance. A complicating factor was the low luminance, specifically 12.6 candela/m², of the high resolution CRT used in this study. At low luminance, the performance of the eye falls off markedly on these detection tasks. The MTF of the display also affects high resolution performance, although we have no specific data to support this observation for the CRT used in this study.

Table 1. Area under the ROC curve for each modality for three diseases.

Abnormality	CF	Digital Film	CRT
Pneumothorax	.98(.010)	.98(.013)	.90(.041)
Interstitial Disease	.92(.019)	.88(.021)	.84(.034)
Parenchymal Mass	.86(.046)	.96(.014)	.95(.020)

B. Phosphor Plate Venography

The group with experience in CR, readers 4, 6, 7, and 8, performed significantly better on CR than CF. The inexperienced group performed at the same level on CR and CF. The experienced group on CR also out-performed the inexperienced group on CR and CF. Total group performance, however, was not significantly different on CR and CF (Table 2).

Table 2. ROC areas for venograms.

Reader	CF	CR
1	.78(.08)	.74(.12)
2	.78(.10)	.68(.10)
3	.70(.10)	.65(.12)
4	.76(.09)	.90(.06)
5	.70(.09)	.76(.10)
6	.78(.09)	.83(.09)
7	.78(.05)	.86(.05)
8	.67(.10)	.91(.05)
Mean	.74(.09)	.79(.10)

C. Musculoskeletal Phosphor Plate Radiography

No significant difference in diagnostic performance was observed between the two modalities for any reader (Table 3). The total performance of the group was not significantly different on CR and CF, nor was there a difference when examinations were grouped by exposure. However, we did note a distinct increase in the noise of CR images especially when the projection was through a thick body part and the exposure was one-half the standard.

Table 3. ROC areas for the detection of musculoskeletal lesions.

Reader	CF	CR	p (two-tailed t-test)
1	.94	.90	.14
2	.92	.87	.11
3	.92	.92	.74
4	.87	.85	.68
5	.91	.87	.21
6	.92	.88	.29
7	.92	.90	.41

IV. Summary

Observer performance using a high-resolution, low-luminance CRT is significantly degraded for a task such as the detection of pneumothorax in a chest radiograph. This is probably due to the modulation transfer function or the low luminance level of the CRT. We note that manufacturers have increased the average luminance of such CRTs so that the results of our study may be modified by subsequent studies. The ability to adjust the contrast, which is a characteristic of most digital systems, is a mixed blessing. It helped in the detection of parenchymal mass where the digital modes out-performed CF, but it hurt in the detection of interstitial disease where CF out-performed both digital modes.

Observer performance using CR may be biased by the prejudices of the participants. It has been impossible to disguise the films, because of the smaller format of CR. However, experience with CR seems to have a positive effect on detection performance as shown in the venogram study. Readers experienced in CR performed significantly better as a group on CR than on CF. All readers performed at the same level on CF.

In the musculoskeletal study, readers may have shown their prejudice as they mostly performed somewhat better on CF than on CR, though not significantly. An advantage of CR is that repeat examinations are reduced because of the wide latitude characteristics of the phosphor plates used. Lower exposure increased the noise in the image, but such images were diagnostic, especially for peripheral projections, e.g. hands or feet. Another advantage of CR is due to the possibility of changing the contrast. A future study will compare CR and CF for the detection of low contrast objects, e.g. tumors or soft tissue injury.

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Preliminary Data on the Use of Stimulable Phosphor Technology in the Investigation of Children with Musculo-Skeletal Disease

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Introduction:

The value of stimulable phosphor technology in a variety of adult examinations is well accepted (1,2,3,4,5,6). However the clinical value in pediatric musculo-skeletal disease has not so far been assessed and the algorithms have not been developed for optimum imaging the different patient sizes encountered in North American pediatrics (7). We are in the process of investigating the value of this technology in comparison to our usual 400 speed conventional film-screen combination in pediatric musculo-skeletal disease.

Materials and Method:

Since September 1990, a digital radiographic system, Fuji AC1, (stimulable phosphor system, Photostimulable Luminescent Device system) has been installed at the British Columbia's Children's Hospital in Vancouver to investigate pediatric musculo-skeletal disease. We have more recently installed a F500 workstation to aid evaluation of the algorithms required. In the near future, an AC2 Image plate reader, a CRLP 414 Laser Image Recorder, a HI-C653F workstation, and a FCR-7502 Radiographic Table with two position

monitors will be installed as well as a card reader interface to our existing MARSII information system.

Double book film/screen cassettes were made up using the routine 400 speed film screen combination available at our hospital, but with an attached stimuable phosphor plate (Photostimulable Luminescent Device) behind in a similar method to previous reports (3). 14 x 17 and 10 x 12 cassettes were made to cover the spectrum of sizes of children seen.

An on-going series of patients who are being investigated for a variety of musculo-skeletal disorders are being studied using this double rather than the standard single cassettes. Each examination used our usual x-ray exposure to expose not just the ordinary cassette but also the stimuable phosphor, at no disadvantage to the patient or quality of the routine film.

A digital radiographic system (Fuji AC1) is used to process the stimuable phosphor plates utilizing contrast and spatial frequency processing. Using phantoms, algorithms and other parameters has already been assessed at our hospital and optimized for visual appearance and pre-programmed into the digital radiographic system (Fuji AC1). A variety of algorithms were found to be necessary depending on the type of image taken.

The digital film and conventional film are viewed independently by a variety of radiologists. On some types of examination, such as scoliosis, an assessment has made of objective and subjective criteria. For these examinations, each radiologist viewed each image on three separate occasions at least one week apart. The digital film and conventional film were not viewed together,

but at least two weeks apart to reduce subjective bias and direct comparison.

The results of previous viewings were unknown. The independent assessment by each viewer was to enable standard deviations of inter- and intra- observer error to be calculated.

Each image was assessed for objective and subjective criteria eg the following parameters were used for scoliosis images:

On the antero-posterior view, thoracic and lumbar scoliosis angles, number of vertebral bodies, number of disc spaces, and number of pedicles were all assessed, as well as the number of end plates seen, the number of spinous processes and the number of rib levels seen well to the coning on one side.

On the lateral view, thoraco-lumbar lordosis/kyphosis angles, number of vertebral bodies, number of disc spaces, number of end plates and number of posterior vertebral markings seen were all assessed.

The components of the AP and lateral view were added to form a composite score. Those scores were used in the assessment of the clarity of vertebral visualization.

In addition, for many examinations, a more subjective overall assessment of the appearance is made on a scale of 1 to 5 as per the scale shown below:

- 1 = Film needs repeating, as undiagnostic,
- 2 = Film needs bright light for interpretation,
- 3 = Film is just adequate without bright light,

- 4 = Film is good with negligible areas difficult to see,
- 5 = Film is excellent.

The study protocol was passed by the Ethical Committees of the University of British Columbia and the BC Children's Hospital.

Results:

A variety of musculo-skeletal diseases are under investigation and some of our preliminary results will be demonstrated and are discussed below:

1. Scoliosis X-rays

Scoliosis is a common debilitating deformity of the spine found in a variety of neurological disorders as well as found in many otherwise normal children.

In a prospective study of 100 patients and over 16,000 separate observations, 3 radiologists preferred the digital image and structures were visualized more often and more reliably.

2. Other spine X-rays

As with scoliosis examinations, other spine views can pose major exposure problems due to the different thicknesses of tissue that have to be penetrated eg. L1 vs. L5/S1 on the lateral views. The initial results have shown the technology to be most helpful in a similar manner to our scoliosis series.

3. Fractures

Trauma, with the possibility of fracture, makes up a large part of our case load. Initial digital images have shown excellent promise at being able to increase the conspicuity of subtle fractures. This has been clearly seen in a number of instances with some fractures clearly seen on the digital image which are not visible on the standard image. In addition, extent of fractures seen on digital images may be shown to be more extensive than previously suspected from the conventional films.

4. Soft tissue and bone tumours

Background: Soft tissue and bone tumours are relatively uncommon pediatric problems, however they are always very labour intensive and require the ultimate in diagnostic technique both at time of presentation and follow up. We have found the digital images demonstrate the extent of the soft tissue mass better than the plain film.

5. Foreign bodies

Background: Young children often swallow unusual objects. Because of the wide differences in exposure of the radiographs in these children, the digital images are ideal at delineating the foreign body.

6. Skull, sinus, and lateral neck X-rays

Background: The digital images have always been at least as good, and usually better than the conventional films. The latitude of the system has enabled excellent visualization of cervical spine, airway and soft tissues.

SESSION 8

Research

Chair: Heinz U. Lemke

An Object-Oriented Representation of Data from Medical Images

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1. INTRODUCTION

Diagnosis and treatment planning of a patient is often guided by information from medical images. Over a certain period of time several examinations will take place, whose information content will add to give an image of the patient. Decisions on the number and the kind of examinations will depend on knowledge derived before and during diagnosis and treatment. Thus, patient information to be represented in a computer assisted environment can be characterized as being of varying type and number.

Categorization of the information can be done by means of the different contexts in a hospital. Information may be understood as being part of a patient description, of a certain therapy, or of an administration process. Each of these categories results in a different concept of organising the information. The concepts have only a theoretical value, as long as different types of information are used independently of each other, since in this case integration of information needs not to be supported by the computer. However, as the number of medical images increases, there is a growing possibility to utilize more than one source of information for computer assisted diagnosis and treatment planning. The information includes - besides the content of medical images - additional knowledge, such as treatment simulation data or analytical models. The diversity poses several problems to the integration in a common information structure:

- Each kind of information has its own, unique solution for its optimal representation (regarding, e.g., storage efficiency, ease of access, etc.).
- Different representations require different access methods to the information contained in it. The management of different access methods has to be done by the integrating system.
- The combined access to different representations requires new methods for each combination. This may lead to an exploding number of methods, especially, if the number of combinations remains unspecified.
- Varying applications work on changing subsets of the total number of representations. Thus, keeping representations, which are not used for a specific purpose, leads to an inefficient representation.

For these reasons integration happened either punctually to serve a specific purpose (see, e.g., /Pize89/) or by forcing all the information needed in one basic structure (see, e.g., /Toen90/). The former is application-dependent and, therefore, new methods have to be developed when a new application requires a new type of representation. The latter is application-independent, if a basic representation can be found by which arbitrary information can be expressed, but it tends to be slow, because the basic representation is often inefficient.

In this paper we present a new approach for an heterogeneous representation of knowledge on or about medical images, which is flexible enough to serve different purposes in diagnosis and treatment planning and also efficient in that it allows any part of information to be represented in the most appropriate way.

2. AN OBJECT-ORIENTED APPROACH TO 3D REPRESENTATION

The high diversity of information types and the fact, that most of these types are exclusively connected to their own manipulation algorithms, has led us to the approach of developing a Heterogeneous Object-Oriented Representation System (HOORS). The concepts of object-oriented programming seem to be well suited to solve the problems stated above. According to /Bert91/, who developed concepts of an object-oriented data base management system, the paradigm of object-oriented programming can be summarized as follows:

- Each real world entity is modeled by an object associated with a unique identifier.
- Each object has its set of instance attributes being themselves objects or sets of objects and methods defined on the object.
- The attributed values represent the state of the object which may be changed by sending messages to the object to invoke a method.
- Objects of the same structure and behaviour are grouped into classes.
- A class can be a specialization (subclass) of another class inheriting methods and attributed from the superclass.

In the context of representing knowledge from medical images we are dealing with objects which represent aspects related to anatomy and physiology of the human body. The attributes of these objects consist of parameters to specialize the representation and of methods to create another object for the purpose of rendering the information to the user. Information on the patient can be classified by

- its dimensionality.
- the underlying model (e.g. for 3D representations a surface or a volume model).
- the way reality is modeled (approximative, interpolative).
- the way the representation is done (synthetically, that is by enumerating a set of primitives, or analytically, that is by a closed form of a set of functions).

the application planned to be executed on a representation of the information.

A CT sequence, represented by a cell enumeration representation, would be a 3D data set, based on a volume model, interpolated and represented synthetically by enumerating voxel values, and, for example, used for radiation treatment planning. The first four classification structures order the type of attributes for object description and the kind of methods, which can be applied to the objects, thus having an influence on the structure of classes and subclasses, while the latter specifies the subset of objects actually used in a certain application environment.

A representation offering all the possibilities listed above would have the disadvantages of being very difficult to handle because of its wide variety of representations and of being fixed to a certain state of the art requiring re-developments for new kinds of information representation. An object-oriented strategy, however, leaves the problems of managing subsets of objects and updates of the object-system to the underlying programming language. Objects and classes serve as templates for an application by which an appropriate subset of objects may be chosen. New methods can easily be integrated without invalidating the existing framework. The introduction of new objects or classes of objects is facilitated by the possibility of integrating them into the existing class hierarchy inheriting methods and attributes of existing superclasses. In comparison to homogeneous representations, such as suggested by /Stie87/, a heterogeneous representation system permits any information to be represented in its own, efficient way. At the same time an application-independent development tool is provided to create instances of representation systems.

3. A PRELIMINARY IMPLEMENTATION

Realisation of the object-oriented paradigm requires careful consideration of the different types of information structures imposed on the information. The first such structure, which is needed for development, is the inheritance hierarchy. This hierarchy describes how attributes of classes are inherited from other classes. A class 'Discrete Object Representation', for instance, may inherit all the attributes of a superclass '3D Scene'.

In our implementation we restricted ourselves to a single-inheritance scheme although multiple inheritance schemes do exist lacking, however, proper definition (there are, for example, consistency problems in the case of attributes with the same name in different objects). Using single-inheritance the hierarchy becomes a tree defining different kinds of levels on which information may be represented. Thus, the inheritance tree is of great importance for a developer designing or modifying a HOORS. For the user, it is invisible, since he does not need to know, where attributes are defined within the tree. In our preliminary design, we included classes in the system which represent inner points as well as boundary points of objects of varying dimensionality, namely:

- the class 2D-CE (2D cell enumeration representation).

- the class **3D-CE** (3D cell enumeration representation with isotropic voxels).
- the class **3D-vary** (3D cell enumeration representation with anisotropic voxels).
- the class **cuberille** (3D discrete boundary representation, see /Liu77/).
- the class **polygon** (3D surface approximation, e.g., by a triangulation /Fuch77/).

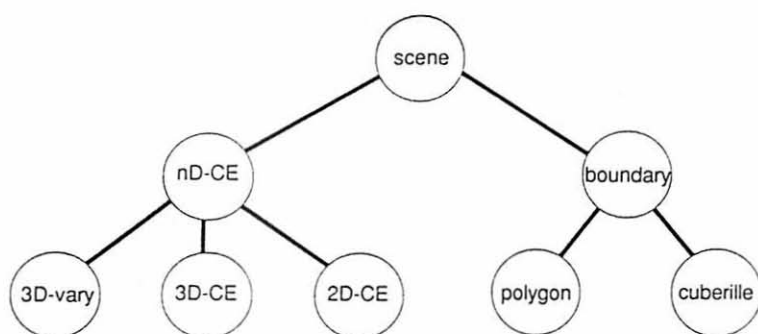


Figure 1: Inheritance hierarchy of the HOORS

These classes constitute an inheritance-tree as depicted in Figure 1, forming superclasses **boundary** and **nD-CE** which themselves are subclasses of a class **scene**. Methods and attributes were defined for these classes, keeping in mind that a class inherits all attributes of its superclass.

Including a new type of representation in the HOORS - e.g., a class **4-dimensional-CE** - would not invalidate the system, since simply a new node would be added to the inheritance tree. If, as it is the case in our example, it would be a subclass of some other node (the node **nD-CE** in the example), it would inherit all the attributes of the superclass. If the new class is independent of the existing classes - e.g., a class **text** - then the developer would have to consider, whether the new node and the existing root share certain attributes and are subclasses of some new root (e.g., **patient information**).

Nothing should change regarding already existing instances of the HOORS. This makes object-oriented modeling so attractive for the representation of patient information. The system is open to changes and compatibility is ensured by a programming language conforming to the object-oriented paradigm.

Structuring the use of a representation requires a second static structure on the objects which we call the *usage scheme*. Classes use their subclasses. Thus, a part of the usage scheme is the inverse of the inheritance tree. However, there are applications - e.g., registering a surface and a volume representation - which use the classes - the classes **3D-CE** and **polygon** in the example - without passing its attributes on to them. Thus, the usage scheme is not simply the inversion of the inheritance tree. It also

constitutes an application-dependent data organisation. At present, our application algorithms include methods to render 3D data and to convert between volume and surface representations. These two methods would require classes using objects of other classes while *not* passing attributes to them. However, as we shall see later, it is nevertheless advantageous to attribute these methods to those classes whose objects constitute the input data of the method.

It is important to remember, that generation and manipulation of objects is not controlled by the inheritance hierarchy. A surface representation, for instance, may very well be created from a discrete volume representation by an application object using the two objects. This does not contradict the object-oriented paradigm, since inheritance-trees are used only for the purpose of developing and not for using the scheme.

4. RESULTS

The designed representation system was implemented with the exception of the classes **3D-vary** and **polygon**. We used the language C++ which, despite of several shortcomings, has the advantage of being widespread and easy to be used in connection with conventional C-code.

Objects to be defined consist of a public and a private part. Attributes being private can only be used by another object via passing a message to this object requesting the information from this object using one of its public methods. In order to convene with the object-oriented paradigm, we decided to keep the data of an object private. Methods using the data are public (attributes of the classes are shown in Figure 2).

Besides descriptive information and methods to create, store and destroy objects, several 2D- and 3D-manipulation and -visualization algorithms are implemented, namely

- the generation of a histogram from a 2D or 3D scene.
- filtering methods for smoothing and edge-enhancing 2D images.
- algorithms for histogram equalization on 2D- and 3D-images.
- the generation of a 3D region-of-interest (ROI).
- threshold segmentation on 3D images.
- slice extraction from 3D images.
- surface rendering of a cuberille representation.
- volume rendering of a 3D CE.
- conversion of a segmented 3D scene into a cuberille representation.

The last four methods result in objects of a different class than the class in which the method is defined. According to our argumentation on the usage scheme this would require a separate class using the classes of the input and the output data. In this case, data access times would increase, because access to private attributes of an object from an object of another class cannot happen directly, but through public access methods of this object. Consistency and validity of the information request need to be

checked for each access. A method of the object itself has, on the other hand, immediate access to all the information in the object.

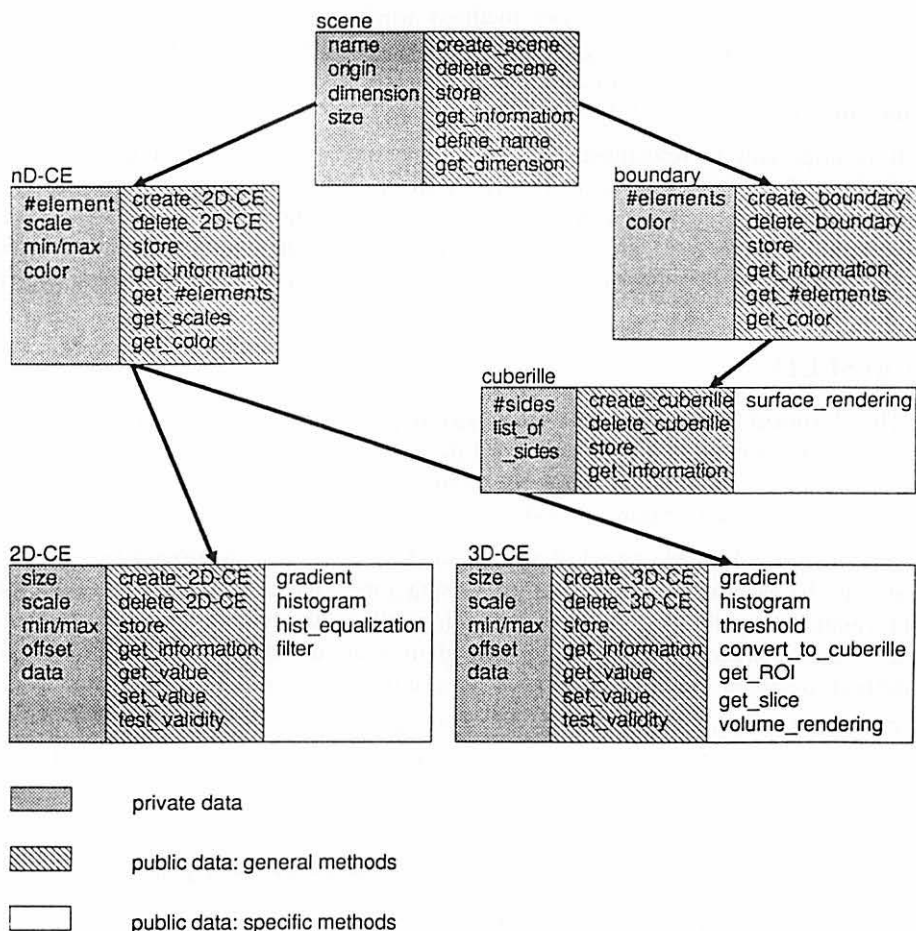


Figure 2: Important attributes of the classes in the HOORS.

We compared the HOORS to a previously implemented XCE-representation /Daun91/. An XCE representation is a homogeneous representation scheme derived from a generalization of a cell enumeration representation /Stie87/, where each cell represents values of several functions. To put this concept into practice a description graph is required to show how function values are represented in a cell of the XCE representation /Toen90/. This increased access times approximately fivefold, since each access has to be realized through the graph, and the cell has to be decomposed prior to using its information content (see /Daun91/, /Toen91/ for details). In the HOORS these impediments do not exist. As expected, access times were just about 20% slower than the time for simple data assignment to variables. The 20% can be attributed to the overhead of the structure of the representation scheme.

5. CONCLUSIONS

In our preliminary evaluation the HOORS was found to be a flexible tool for representing heterogeneously described information, because the HOORS is

- capable to support any kind of data description in its own optimal way.
- open to the addition of new representation forms without invalidating existing representation forms in the system.
- offering fast access to the represented data.

In all the three points noted above the concept of heterogeneous information representation does have advantages over a homogeneous representation concept such as the XCE representation. The major disadvantage is the complexity of the data structures defying, for example, hardware support for the representation (not for the methods!) and complicating the development of a system. The latter, however, is supported by using a programming language, whose structures support object oriented strategies to solve problems.

However, the usefulness of this concept can be tested only if representations schemes for varying application are created from it. Therefore, our future research will concentrate on the development of tools to create application-specific representation schemes using the existing system and the presented concepts as a toolbox. This should enable a developer to create almost arbitrary representation systems from the HOORS.

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Computer Estimates of Bone Strength with Simulated Lytic Lesions Using Dual Energy X-Ray Absorptiometry

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INTRODUCTION

Metastatic lesions to bone are common, especially with lung and breast cancer. Pathologic fractures involving these lesions occur frequently, can be difficult to treat, and can significantly decrease the quality of the patient's life (1).

Prophylactic internal fixation of these lesions has been shown to reduce the incidence of fracture, reduce pain, and maintain function (2-6). The decision to perform prophylactic fixation for a lytic bone lesion is a difficult one. Current clinical criteria for prophylactic fixation include: 1) a well defined lytic lesion 2.5 cm. in diameter or larger involving the cortex; 2) destruction of 50% or more of the cortex; or 3) continued pain at the site of the lesion despite radiation treatment (1,7,8). Unfortunately, these criteria too often overestimate the need for prophylaxis or miss lesions that do fracture. More than one-half of observed lesions cannot be evaluated using the accepted criteria (9).

These observations are not surprising since the accepted criteria neither measure nor account for the geometric and mechanical properties that define bone strength. If such information could be acquired non-invasively, the decision to perform prophylactic internal fixation would be based upon an improved assessment of fracture risk. Cross-sectional geometric properties of bone have been derived from radiographic and absorptiometric data (10-13).

Dual energy x-ray absorptiometry (DXA) is a new imaging technique designed for measurement of bone mineral that is easy to perform and costs much less than computed tomography. We have developed special image analysis computer programs and DXA scanning techniques that provide measurements of structural properties from the scan data (13). Along with the conventional bone mass measurement, our programs derive: cross-sectional area and cross-sectional moments of inertia. If orthogonal projections are obtained, as in this study, polar moments of inertia can also be derived. The current investigation is an attempt to employ the DXA methodology as a means to measure strength reduction due to experimentally induced endosteal lesions in femoral diaphysis specimens.

METHODS

The Bone Structure Analysis (BSA) computer program uses image analysis techniques with bone mass image data. The program obtains profiles of bone mass perpendicular to the long axis of the bone which are integrated to obtain

the CSA. The cross-sectional moments of inertia are derived from the integral of dm (the individual bone mass point) times the square of the displacement from the profile centroid (Figure 1). Polar moments of inertia are obtained as the sum of the corresponding cross-sectional moments of inertia, from orthogonal projections. An example of a series of bone mass profiles along the length of a bone segment is illustrated as a surface plot in Figure 2.

Twelve pairs of fresh frozen human femurs were utilized, each consisting of the distal two thirds of the femur. Experimental lesions were created in one of each pair with the unaltered femur serving as a control. Various sized endosteal lesions were surgically created using a cylindrical radius end burr. Both ends of the femoral specimens were potted in aluminum channel. Specimens were immersed in 15 cm of water and DXA scanned (Norland XR26, Fort Atkinson, WI) in both AP and ML projections using the Norland XR26 software and data acquisition board. For comparative measures, specimens were radiographed in AP and ML projections, and underwent computed tomography scanning with 2 x 2 mm slices using Somatom DR-H and Plus scanners (Siemens Medical Systems, Iselin, NJ). Figures 3-5

The DXA projection data were then transferred to a freestanding microcomputer (486DX 25 MHz, Dell Computer Corp. Austin TX) and calculations were made of cross-sectional areas (CSA), cross-sectional moments of inertia (CSMI), and polar moments of inertia (J), using the BSA program.

Following the imaging studies, the bones were tested to failure in torsion at a constant 6° per second using an MTS Bionix 858 materials testing system (MTS Inc. Minneapolis, MN). The maximum torque for each bone was calculated from its measured torque-angular deflection curve (see example in Figure 6).

The relationships of the measured torsional strength to CSA, J and DXA derived torsional strength were analyzed by the method of linear regression. Additionally, the relationships of the measured torsional strength to lesion size (measured from radiographs, assuming elliptical lesions) and percent thickness of the cortex removed (measured from CT) were also analyzed by linear regression.

RESULTS

All specimens fractured in a spiral pattern; in all bones with lesions, the crack passed through the lesion. The bones failed at torques ranging from 37 to 150 Nm in lesion bones and 63 to 170 Nm in non-lesion bones. The endosteal lesions caused reductions in strength between 25 and 87% as compared to the contralateral femur. The lesions ranged from 3 to 6 cm. in length and removed from 10 to 100% of the thickness of the involved cortex as determined from the CT scans.

Using linear regression analysis, the measured torsional strength was shown to be correlated to CSA ($r=0.861$), minimum polar moment ($r = 0.881$), and the minimum DXA estimated torsional strength ($r = 0.866$). All were significant at $p<0.01$ (Figures 7-10, respectively). The measured torsional strength was not significantly correlated to lesion size as measured from the radiographs ($r = 0.542$) or to percent thickness of cortex removed ($r = 0.257$).

DISCUSSION

The results demonstrate that orthogonal (AP and ML) DXA scans with the Bone Structural Analysis (BSA) program provide an improved method for

estimation of strength reduction produced by lytic bone lesions involving the diaphysis, particularly in comparison to current qualitative clinical methods.

Good correlations were obtained between measured torsional strength and DXA estimated torsional strength, polar moments of inertia, and cross-sectional areas. These results were obtained without correcting for the additional stress riser produced by lesions piercing the cortical wall. We suspect that inclusion of a stress riser would improve the strength estimates. However, by not correcting for this the clinical setting was more closely replicated. In practice, we expect a lytic lesion to be detected on initial films or a skeletal survey and a referral for a DXA study to be made. Most of the time the percent involvement of the cortical thickness will not be known from the radiographs unless additional oblique views are obtained which place the lesion in profile. We are investigating a number of approaches that would provide an estimate of the stress riser from DXA data.

Simple description of the lesion, by size (approximated by an ellipse from the radiographs) or by the percent cortex removed (measured from CT) was not useful as an estimation of strength.

CONCLUSION

We feel that DXA may be useful clinically to predict strength in the diaphysis of bones with lytic lesions, that such an application would be easy and economical, and its use would provide key information in making a difficult clinical decision.

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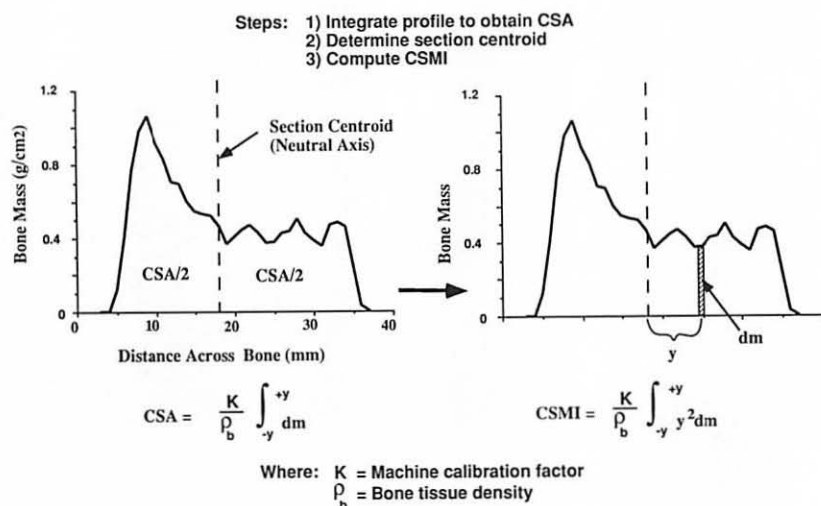


FIGURE 1: Derivation of sectional properties from bone mass profiles

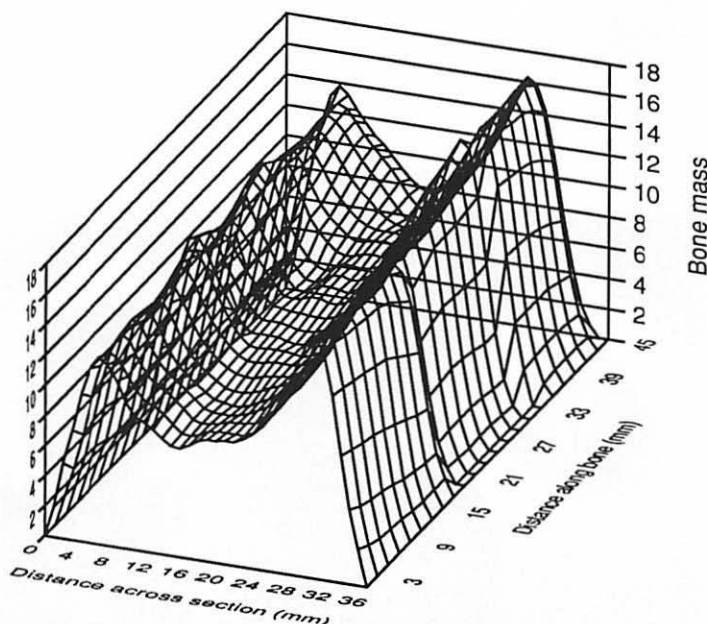


FIGURE 2: Series of bone mass profiles along a femur segment

FIGURE 3

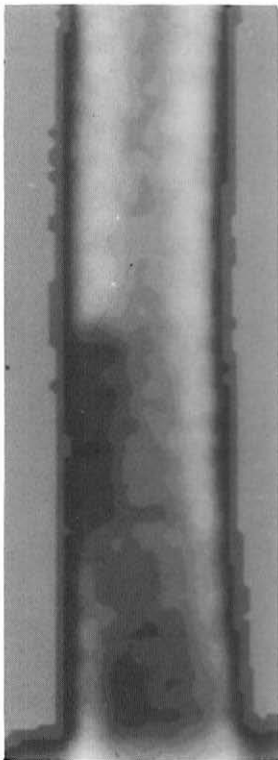


FIGURE 4

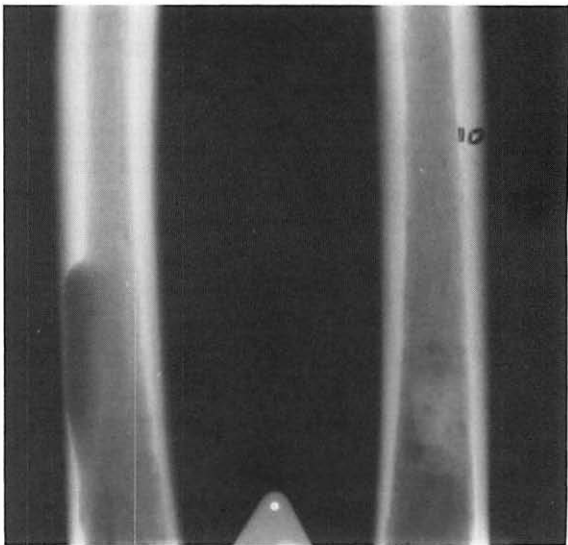


FIGURE 3: DXA image of the bone with lesion.
FIGURE 4: Radiograph of one femur pair. Lesion bone on left.

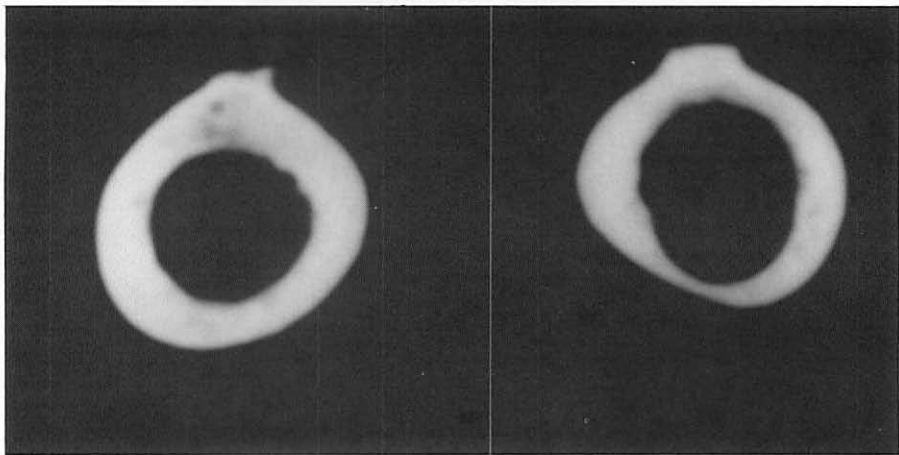


FIGURE 5: CT scan through the area of the lesion demonstrated in Figure 3.

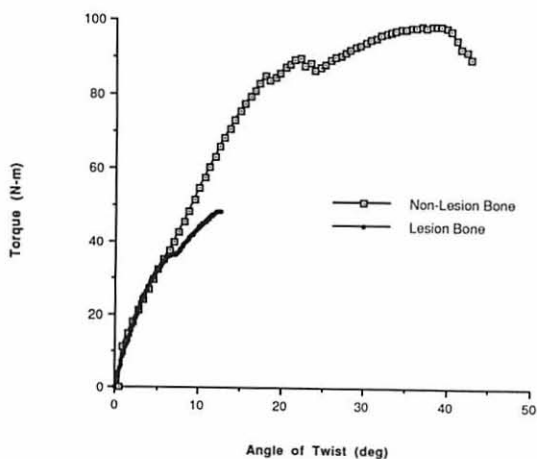


FIGURE 6: Torque versus twist angle curves. Nonlesion bone curve on top.

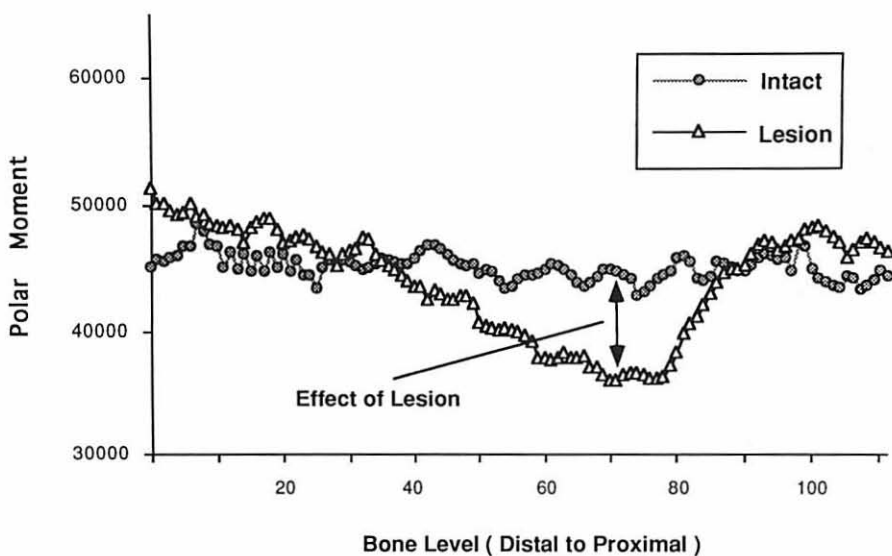


FIGURE 7: Polar moment plot along the length of a femur. Note the effect of the lesion (arrow).

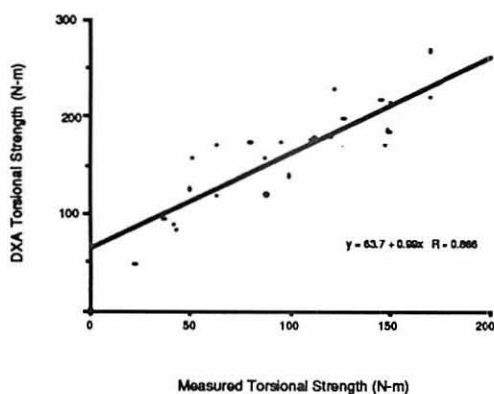


FIGURE 8: DXA estimated torsional strength versus measured torsional strength.

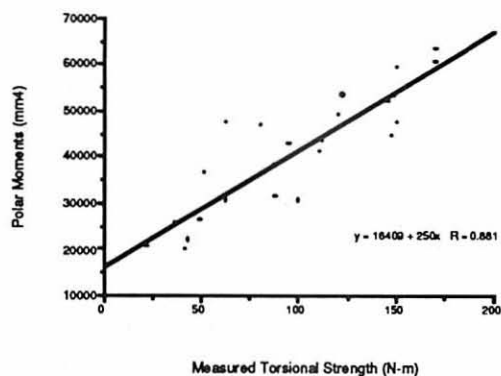


FIGURE 9: Polar moment of inertia versus measured torsional strength

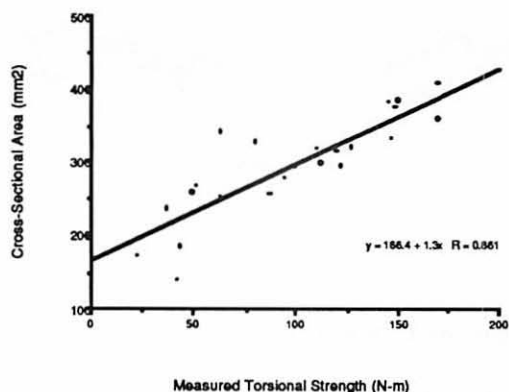


FIGURE 10: CSA versus measured torsional strength.

Modeling of Plain Film Radiography with CT Data

Jeffrey R. Crass, M.D.

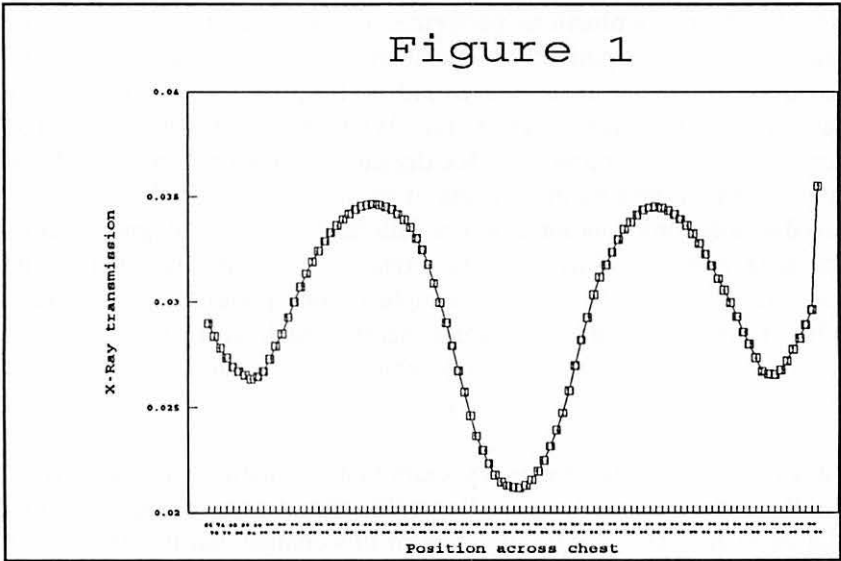
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Computerized tomography has been in active clinical use for only two decades. In that time, however, the method has become a mainstay of medical practice. It is estimated that there are about 60 imagers per one million inhabitants of the United States.¹ During 1990, there was an excess of 1,399,280 studies of the brain, 587,942 abdominal examinations, and 188,736 chest examinations performed on hospital inpatients.² Accurate data on ambulatory patients is unavailable. These studies have resulted in the saving of many lives and countless hospital days as early accurate diagnosis can decrease length of stay. Whereas most institutions retain film records of these examinations, the digital information is usually discarded after several months by the process of reuse of the archival magnetic tapes. This discarded information contains data far beyond the diagnostic clues for individual patients. Anatomic and attenuation information on a millimeter scale are contained for a large sample of our population. In excess of 1×10^{13} pixels of information are generated each year; such data can be tapped for population based studies which might otherwise not be possible. This report describes one such study.

It has been recognized for many years that if a patient is rotated from the true PA position the relative radiographic film density changes on one side relative to the other.³ The direction of this change and the anatomic basis has not been defined. There has even been uncertainty as to its direction.⁴ "Correctly" aligned films do not exhibit the phenomenon; study in a film based experiment would require radiographing a population of subjects at a number of different angles, performing densitometric analyses of the films, and correlating the densitometry of the physique of the subjects. Not only would such a study be laborious, the requirement for multiple repeat radiographs makes it ethically impossible for radiation safety issues. We utilized the density information encoded in routine chest CT data to perform this experiment with no subject risk.

Methods

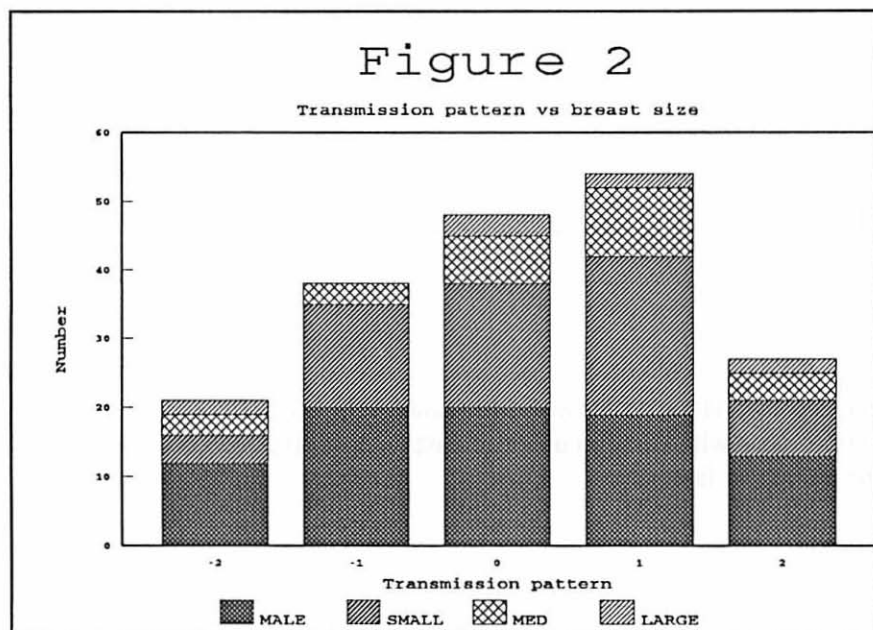
Digital CT data from three CT slices on each of 68 consecutive patients undergoing routine diagnostic studies formed the study database. This information was transferred to floppy disk for archival storage. With the cooperation of the vendor (Picker International, Inc., Solon, OH), software was written to allow these images to be read into a microcomputer. Utilizing a ray projection algorithm⁵ the x-ray transmission through the patient could be calculated by the computer, and a profile of the transmission pattern generated for any angle (we used 13 angles -30 degrees to +30 degrees). We sampled 100 points across the thoracic slice for each angle measurement. A typical density profile is shown below. Note the peaks of x-ray transmission through the lungs.



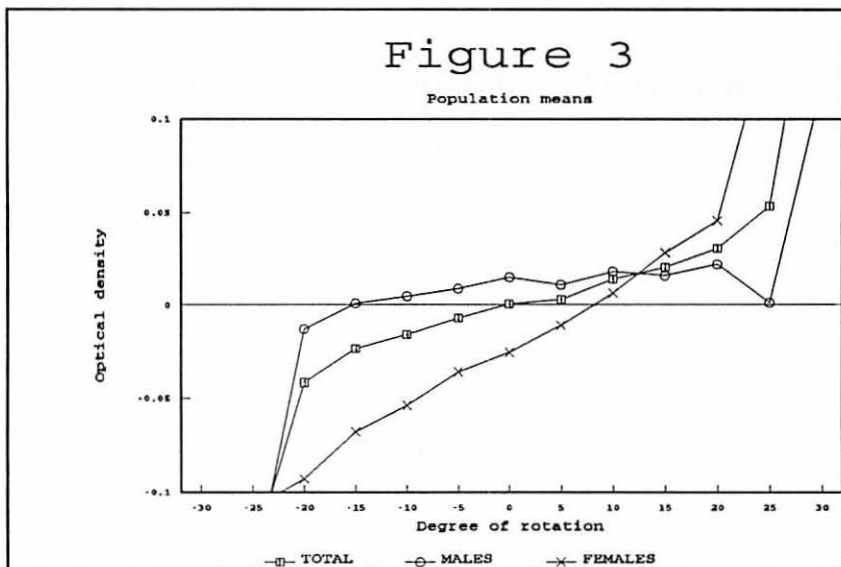
Once generated the patterns of density change were studied in correlation with the amount of breast and pectoral musculature, the body habitus, and the general thoracic anatomy.

Results

Analysis of the pattern of x-ray transmission with rotation showed a trend of increased transmission contralateral to the side which was anteriorly oblique relative to the film plane. This was statistically significant in the mesomorphic subgroup ($p=.04$) and nearly significant when related to breast size ($p=.054$).



The pooled data revealed a near linear relationship between the angle of rotation and the difference between the peak transmission through the hemithoraces. This was the same trend noted in the pattern analysis results. This trend was strongest in the female subgroup.



Analysis of phantoms showed little change in the difference between the hemithoraces with rotation unless breast/pectoral tissue was present. Body size was not a factor.

Discussion

The application of computer methods has great potential in solving problems which cannot be studied by classical methods. Our project could not be performed by direct methods because of radiation safety constraints. Utilizing archived data, however, we were able to solve a problem which has eluded a solution for decades.

When we reviewed the experimental data in correlation with the CT images, the source of the phenomena became readily apparent. Posteriorly the body wall is thicker laterally and medially. In the mid-hemithorax posteriorly there is a relative window which is responsible for the zone of maximal transmission. Anteriorly there is much greater variability. The majority of patients have the least body wall thickness medially anteriorly. As one looks laterally most patients become thicker either as a manifestation of breast tissue, pectoral muscle mass, or a combination of the two. The changes one sees as a function of rotation are due to the projection of different areas of the tapered anterior body wall through the posterior area of thin body wall.

The general availability of powerful microcomputers and of digital data from CT or MR instruments suggest that methods such as ours could become significant for gross anatomic population studies. Increasing availability of imaging work stations will facilitate this. Such studies in the past required either surgical or autopsy data; this yielded major potential for "recruitment" bias, particularly in regard to disease severity and age. This is becoming a more significant problem recently as the rate of autopsies is generally decreasing. By using a CT based computer method, every patient undergoing a diagnostic scan is a potential research subject without any risk or consent needs.

There are, of course, some limitations to the CT method. Recruitment bias is a potential problem here as well. Most people undergoing CT studies have an ongoing disease process which must be controlled for in the selection process. Consultation with the medical record should eliminate most problems in that regard.

In our study the disease processes present may have skewed the population, particularly in the male patients. It is probable that our patients in general had less muscle mass than healthy subjects. This would not affect the direction of the effect we detected but might have decreased the magnitude. The supine position could also introduce errors in magnitude because of gravitational effects on soft tissues. Chest radiographs are routinely performed in the upright position. Finally, we could not control for nor examine effects which might result from compression of the soft tissues resulting from a patient rotating and pressing one hemithorax against a radiographic unit at the time of exposure.

Potentially more significant are assumptions in the CT method itself. CT images and data are derived information, the result of vendor specific algorithms. The density information portrayed may contain potentially significant variation which should be controlled. This was true to some degree in our study; one notes in figure 3 above the data is shifted slightly above the baseline in a uniform manner. This was confirmed with a phantom to be a result of clinically insignificant slight left to right density differences in the CT data on our instrument.

In spite of these limitations, however, we feel this study has convincingly demonstrated the thoracic anatomic features which result in the rotational phenomena. Similar application of computer methods to the massive database of digital information now available should lead to the solution of many other "unsolvable" problems.

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MRI Statistics and Case Retrieval With a PC Database

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I. INTRODUCTION

An MRI database can be used to enhance the following functions: marketing, productivity, teaching. Although a Radiology Information System (RIS) would be the most convenient way to generate such a data base, a commercial spreadsheet or database system installed on a personal computer can also be used. We describe here a database system that we have developed to analyze MRI use statistics and to assist in retrieval of interesting cases for conferences and reports. The system has been fashioned for use at an in-house MRI installation in a rural tertiary care institution (Geisinger Medical Center) that has a number of satellite clinics. With slight modifications it might also be useful at a free-standing MRI center.

The database, which is derived from a *LOTUS 123™* (v 2.2) spreadsheet, incorporates the following types of information: patient demographics and status; referral, categorized by Medical Center department or off-campus location and by referring physician; attending radiologist/technologist; MRI exam start and end times; exam conditions (e.g. protocol, sedation); charge category. Also, cases of interest may be retrospectively sorted by a coding system with three main categories: I. organ or body area of interest; II. tentative finding; III. follow-up or special interest status. Reports may be generated from the database to yield statistics useful for analyzing productivity and marketing (see below).

II. IMPLEMENTATION OF THE DATABASE

When we started this project, data was entered into the spreadsheet by transcription from MRI forms. These forms had been filled out previously (at various stages of the MRI exam) by a receptionist, technologist and, after the exam was read, by the attending radiologist. We now use direct entry by the MRI technologist, (except for the diagnostic items). To save time and make the data-entry process simple, a macro is invoked that generates a series of prompts for the required entries. A subroutine in this macro yields, from single key-strokes, start,

end, and elapsed times for a given exam. Data-entry is done in the MRI control room via a HP 95LX™ palmtop computer that has LOTUS 123™ preinstalled. This palmtop is not affected by the relatively large magnetic field in the control room (10 to 20 Gauss). For mass storage and analysis of the spreadsheet data, file transfer from the palmtop to a desktop PC is effected by means of a "Connectivity Pack". Representative spreadsheet entries are shown in Fig 1.

PROT	DEPT	AGE	SEX	SED?	DISC	DATE	START	END	TIME	CHARGE#	DIAGNOSIS	REMARKS
mra/h	neur	9	f		44b	3/25	09:15	10:00	00:45	70551		neg
br	ns	57	f		44b	3/25	10:30	11:25	00:55	70553	I14II33III0III1	pos!fup meningioma
crdcm	neph	62	m		44b	3/25	11:30	12:10	00:40	72146	I32II32	pos, spinal mets
crdcm	neph	62	m		44b	3/25	12:10	12:55	00:45	72149	I33II32	pos, spinal mets
ls	gmgl	35	f	y		3/25	13:05	13:15	00:10	nc		claustro
br	peds	2	m	ga	45a	3/26	08:30	09:10	00:40	70551	I13.02II36	pos, craniopharyngioma

Figure 1. Representative entries for the MRI spreadsheet.

In Fig 1, the following data-entry items are omitted for reasons of confidentiality or clarity: hospital ID Number, Name, inpatient status, referring doctor name, MRI study number, attending radiologist/technologist initials, reading radiologist initials. All entries have been excerpted from an actual spreadsheet. The "PROT" refers to the MRI scan protocol menued for the exam, with standard abbreviations (e.g. "crdcm"=cordcompression, "ls"=lumbar spine). The "DEPT" column entries denote the referring department at Geisinger Medical Center, with the exception of the GMGL entry, which stands for Geisinger Medical Group, Lewistown, a Geisinger Affiliate. The "SED?" column shows whether the patient has been sedated ("y" entry) or has been given general anesthesia ("ga" entry). The "DISC" column gives the label for the optical disc on which the scan images are stored. Patient demographic and referral data items are entered before the scan is started.

Date, start time, end time and elapsed exam time ("DATE", "START", "END", "TIME", respectively) are entered from macro subroutines on single keystroke responses to appropriate prompts as the exam is started and ended. Charge Number ("CHARGE#"), proposed finding ("DIAGNOSIS"), and Remarks are transcribed from printed forms after the exam is read.

The "DIAGNOSIS" entries, initially written on a standard exam form by the reading radiologist, are coded as follows. Numbers following "I" refer to location, with nine main categories: 1. Brain/Skull, 2. ENT/Orbit, 3. Spine, 4. Neck, 5. Chest/Med.Stein., 6. Abdomen, 7. Pelvis, 8. Upper Extremities, 9. Lower Extremities. Numbers following "II" refer to finding or diagnosis, with 13 main categories: 1. Normal/Controls, 2. Infection, 3. Neural Neoplasms, 4. Non-neural neoplasms, 5. Trauma, 6. Congenital, 7. Toxic/Metabolic, 8. Vascular, 9. Degeneration, 10. Demyelinating, 11. Internal Organs, 12. Cardiac/Great Vessels, 13. Connective Tissue. Each of the main categories is classified further, as shown by the examples in Table 1. Numbers following "III" refer to exam or case status:

"0" denotes a case of unusual interest, suitable for conference presentation or teaching file; "1" indicates that the exam is a follow-up from a previous MRI exam; "2" indicates that the exam is post-op, following surgery; "3" indicates that the exam follows radiation therapy. Thus the second entry in the "DIAGNOSIS" column in Fig 1 indicates a follow-up exam ("III1") of unusual interest ("III0"), located infratentorially ("II14") in the posterior fossa, and diagnosed as a meningioma ("II33"). The third diagnostic entry in Fig 1, "I32II32", shows a metastatic lesion in the thoracic spine. We should emphasize that this coding system has been adapted from one devised primarily for neuro-radiological studies and is undergoing continual revision as more body MRI studies are carried out.

TABLE 1
CODE FOR LOCATION (I"number")

<u>Brain/Skull</u>	<u>Spine</u>	<u>Lower Extremity</u>
11. Skull	31. Cervical	91. Joints
12. TMJ	32. Thoracic	.01 hip
13. Supratentorial	33. Lumbar	.02 knee
.00 pineal	34. Sacrum	.03 ankle
.01 hypothalamus	35. Brachial Plexus	92. Thigh
.02 pituitary	36. Lumbar Plexus	.01 femur
.03 Optic Chiasm		.02 muscle
.04 ventricle		.03 vessels
.05 parenchyma		.04 sub-cutaneous
14. Infratentorial		93. Lower Leg
15. Cranio-cervical Junction		.01 tib/fib
		.02 muscle
		.03 vessels
		.04 sub-cutaneous
		94. Foot
		as above...

CODE FOR FINDING (II"number")

<u>Infection</u>	<u>Neural Neoplasm</u>
20. HIV/AIDS	30. non-glial/miscellaneous
21. abscess	31. glial neoplasm
22. encephalitis	32. metastasis
23. meningitis	33. meningioma
24. granuloma	34. nerve sheath (eg neurinoma)
25. sarcoidosis	35. pituitary adenoma
26. complication	36. developmental
27. TORCH	
28. discitis	
29. osteomyelitis	

III. REPORTS FROM THE DATABASE

Generation of reports from the database contained in the spreadsheet can be readily carried out by prescriptions outlined in standard texts on *LOTUS 123™* (see, for example, Reference 1). Reports with marketing applications could focus on number of studies by referring department or location, as shown in Fig 2, or on number of studies by age group, referring doctor, etc. Productivity reports will generally deal with time per study, categorized by charge number, attending radiologist, protocol, etc. For example, in Fig 3, the effects of sedation on time per

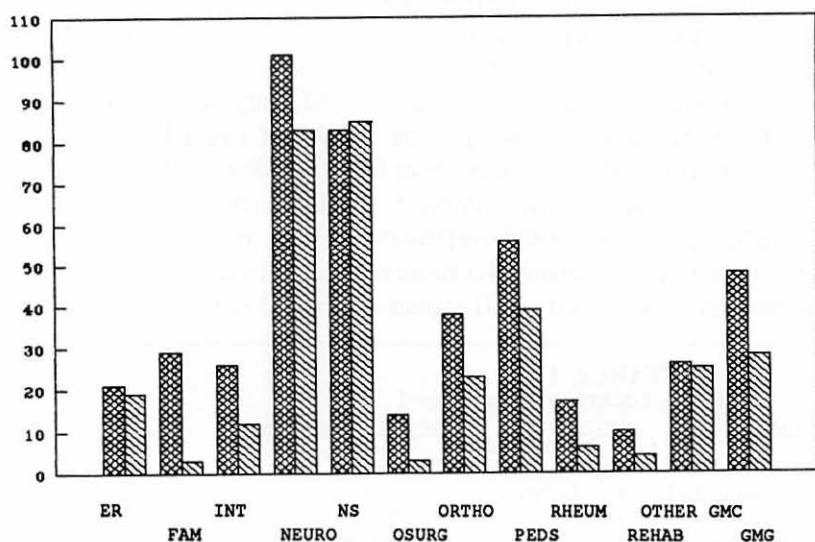


Figure 2. Number of Studies by Referring Department, Nov, 1991 (cross-hatched) vs Nov, 1990 (striped). (Non-Geisinger not listed.)

study and a comparison of time per study for MRA (magnetic resonance angiography) head studies vs non-MRA head studies is shown. The time between successive studies can be calculated by taking the difference between the exam end time and the start time of the following exam. Thus relative time lost between exams due to various conditions (sedation, general anesthesia, claustrophobic reactions) can be estimated by tagging for these conditions, as shown in Fig 4.

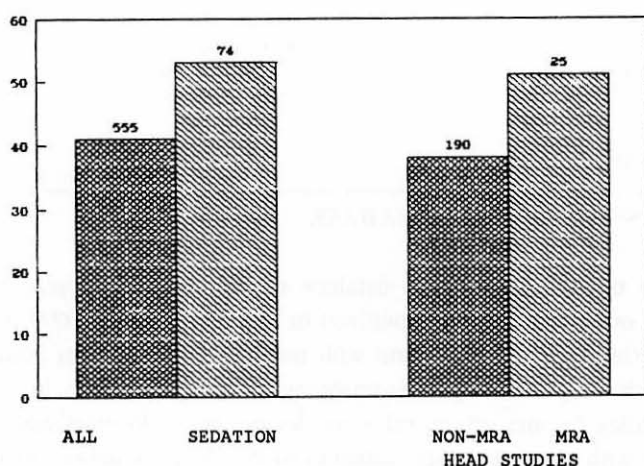


FIGURE 3. Effects of sedation (striped) and MRA (cross-hatched) on average time per study; number of cases indicated above bars.

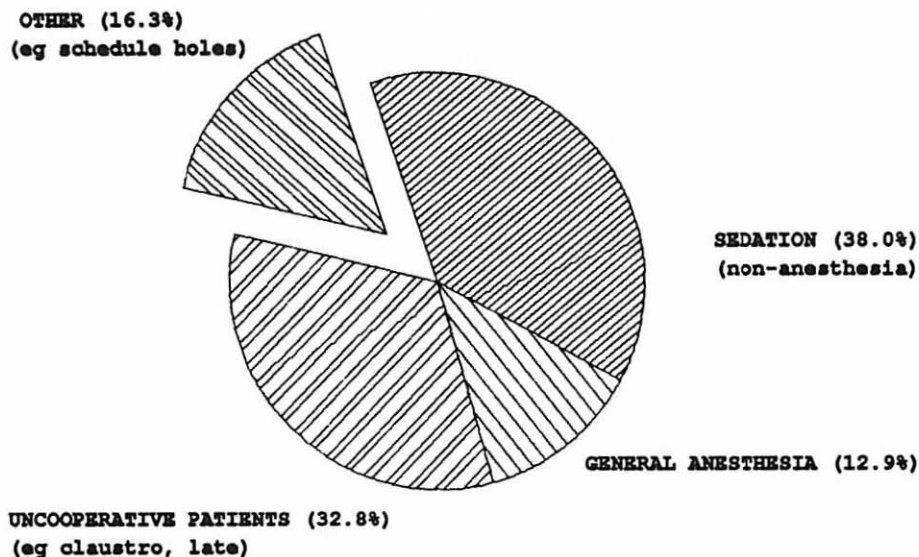


Figure 4: Relative time lost between exams by source (periods under 10 minutes not considered).

IV. DISCUSSION

A personal computer database system like that described here is applicable not only to an MRI installation but also, *mutatis mutandis*, to other modalities. For example, a *Macintosh*TM based system, designed primarily for retrieval of interesting CT cases, has been recently reported². The ease and accuracy of entry of items into the database, as well as the kind of reports that can be generated from it, are important in the design and implementation of a PC based system. In general it is desirable that data be entered directly at the examining site by attending technologists or radiologists. It is particularly important, if productivity reports are to be generated from the database, that a convenient and accurate means for entering exam start and end times be implemented. With the *LOTUS 123*TM spreadsheet, times can be entered with single keystrokes by use of suitable macros. For an MRI installation, the condition that data entry is done at the exam required a magnetically shielded MRI system or, alternatively, use of a PC (laptop or palmtop) not affected by the 10 to 20 Gauss magnetic field present in an unshielded control room. The HP 95 LXTM palmtop, with *LOTUS 123*TM pre-installed, meets this condition. Note that storage discs will be affected by a magnetic field. We have carried out the database sorting required for report writing on a relatively unsophisticated IBM clone: 20 M hard disc memory, 286 processor. File transfer from the HP 95 LXTM laptop to the desktop is carried out on a daily basis.

Clearly an RIS system would be more convenient to use and offer more comprehensive *ad hoc* report writing facilities than the system described here. However, a PC based system is relatively inexpensive and easy to implement, and can be made more convenient by the use of barcode labels and readers at various stages of data entry.

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Objective Evaluation of ACR Mammography Accreditation Phantom Images

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The American College of Radiology (ACR) has established a protocol for accreditation of mammography screening facilities. An important aspect of accreditation is the evaluation of the quality of film images of a standard mammographic phantom (RMI-156). This phantom contains clinically relevant test objects whose visibility on the film image is judged subjectively by three physicists as part of the ACR accreditation protocol. The objects are sets of six fibers, five speck groups, and five masses arranged as shown in Figure 1.

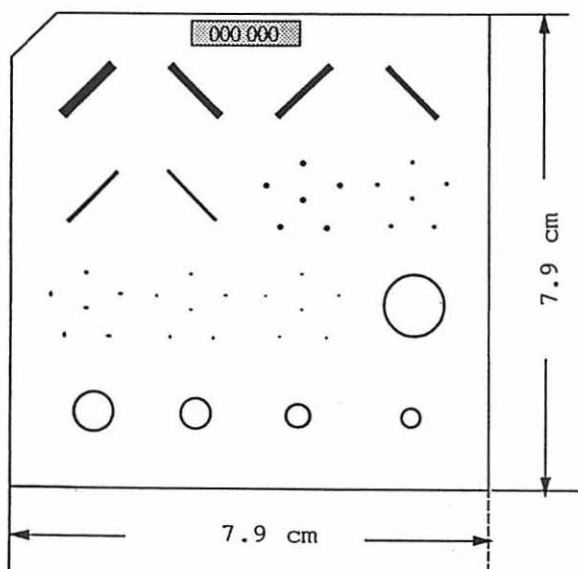


Figure 1. Schematic diagram of RMI-156 phantom

The size of the objects in each phantom object set is listed in Table 1 and was chosen to span the range of clinical findings. The accreditation criterion requires that four fibers, three speck groups, and three masses be judged as visible.

Fiber Width (mm)	Speck Diameter (mm)	Mass Diameter (mm)
1.56	0.54	2.00
1.12	0.40	1.00
0.89	0.32	0.75
0.75	0.24	0.50
0.54	0.16	0.25
0.40		

Table 1. Most significant dimension of objects in RMI-156 phantom

By using a 2K x 2K x 12 bit cooled CCD camera to digitize film images of the ACR mammography accreditation phantom, we have demonstrated that objective digital analysis can be used to determine film image object visibility. The objective analysis was accomplished through use of a computer algorithm which computed the image contrast of each of the test objects in a series of twelve digitized phantom film images. For comparison the twelve test film images were also subjectively judged by five physicists to determine test object visibility and acceptance or rejection under the ACR accreditation criterion.

To quantitate the variability in subjective analysis and to perform the objective analysis, image contrast was defined as the ratio of light intensity for a central portion of each test object to the light intensity of an annulus around the test object as shown in Figure 2. The location of the objects was standardized by first identifying two landmark points on each of the twelve digitized images. Then each image data matrix was translated, rotated, and magnified or minified, respectively, to match the orientation, position, and magnification of a standard template image in which all objects were visible.

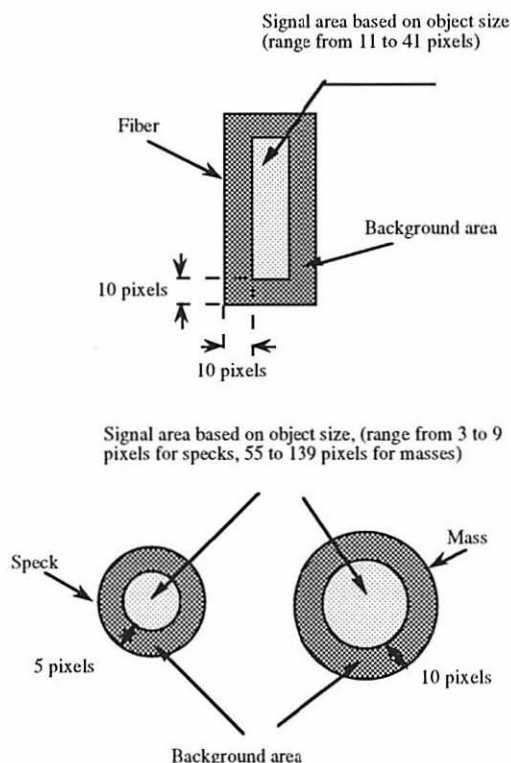


Figure 2. Diagram of the signal and background areas for contrast calculation

Measured contrasts ranged from 1.008 to 1.150 with transition between nonvisible and visible levels falling approximately in the middle of the range for each set of objects as shown in Figures 3-5. The spread in the data reflects the fact that at high and low contrast values all observers agree but at intermediate values there is disagreement about object visibility. The spread in the visibility between physicists was the greatest for the masses. An even greater spread in the visibility was apparent when five radiologist observers viewed the same twelve films.

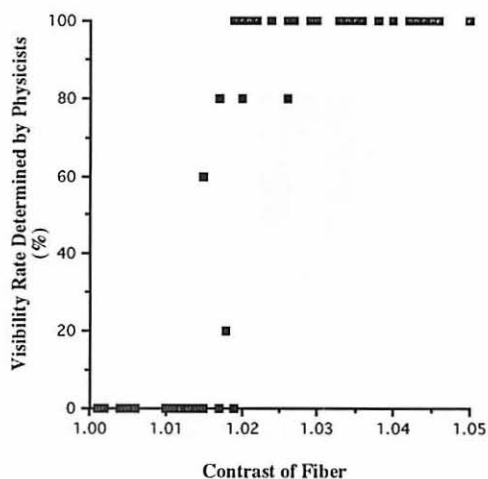


Figure 3. Fiber visibility rate versus contrast

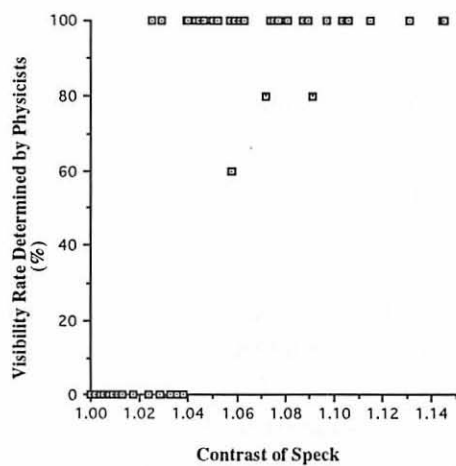


Figure 4. Speck visibility rate versus contrast

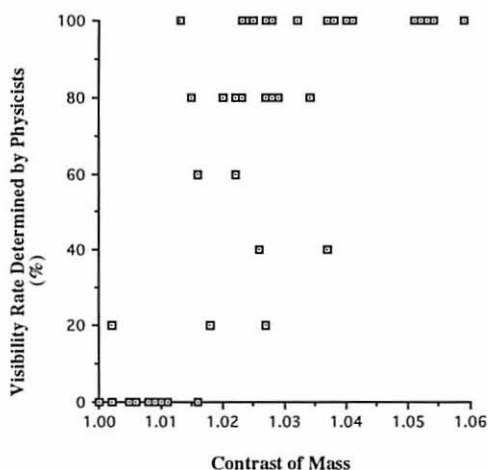


Figure 5. Mass visibility rate versus contrast

The measured contrasts were objectively evaluated by a computer algorithm to determine whether each digitized object image would be visible at a particular threshold comparison contrast value. If the algorithm and a physicist judged a test object to be visible it is called a match. The percent of the total number of objects which matched at each threshold contrast value was referred to as the strict match rate. This strict match rate is shown in Figures 6-8 graphed as a function of

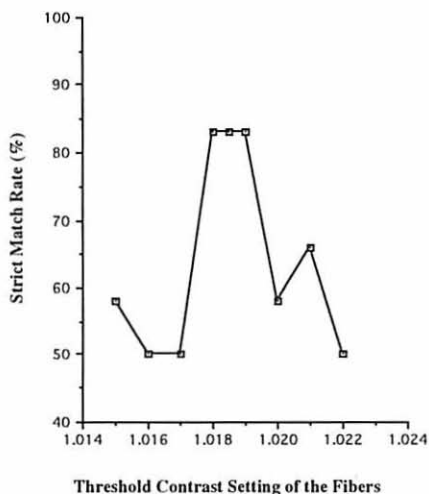


Figure 6. Strict match rate versus threshold contrast setting of the fibers for the evaluation program

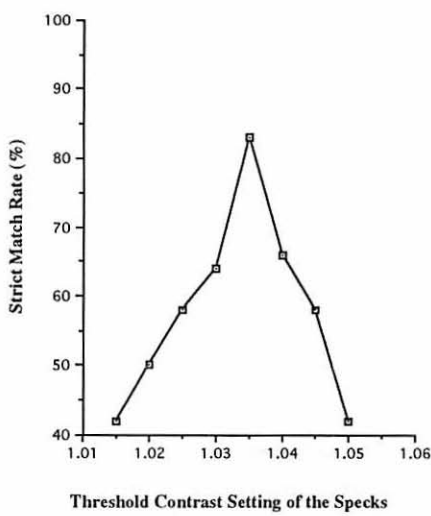


Figure 7. Strict match rate versus threshold contrast setting of the specks for the evaluation program

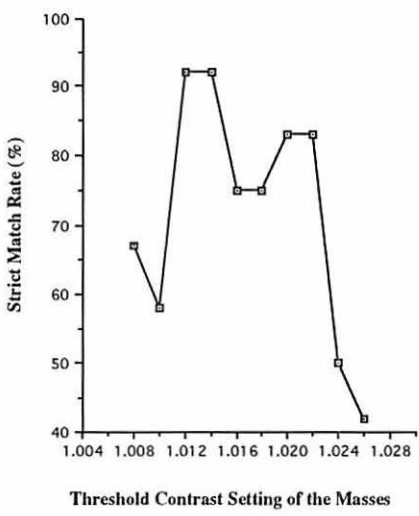


Figure 8. Strict match rate versus threshold contrast setting of the masses for the evaluation program

the threshold contrast setting for the three respective object sets. From the graphs of the strict match rate, the maximum agreement contrast values were determined to be 1.018 for the fibers, 1.035 for the specks, and 1.014 for the masses. Using these contrast threshold values as the visibility criteria our computer algorithm demonstrated 100% objective agreement with the overall image quality acceptability as judged by the five physicists using the ACR criterion.

The present study used only a single test phantom and the computer algorithm required operator identification of two fixed landmarks. Adjustment for image magnification, rotation and translation was included in the algorithm. Future work will focus on developing an object recognition algorithm which is independent of phantom and operator, and provides a totally objective evaluation of the images from multiple replicates of the mammography accreditation phantom.

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Processing and Archiving of Ultrasound Images of Thyroid in Children Irradiated as a Result of the Chernobyl Accident

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I. INTRODUCTION

One of the problems generated by the tragedy of the Chernobyl accident is a problem of arrangement of permanent monitoring of thyroid in children living at areas under observation. This is explained by the fact that the large gush of the radio iodine as a result of the disaster was registered, these radionuclides were accumulated in thyroid of children living at contaminated areas.

The special sensitivity of children thyroid to ionizing radiation was noted previously ¹. Indeed radio iodine was observed in thyroid of 92. 97% of children (younger than 16 years old) and 91. 83% of adolescents (from 16-18 years old), living at contaminated districts. The irradiation of thyroid has been known to result in abnormalities ^{1, 3-5}.

Immediately after the Chernobyl Power Plant (CPP) accident the Government of the USSR had adopted the large scale program on establishment of the National Registry. At present time the data on 86. 7 thousand children (to 14 years old) and 34. 5 thousand adolescents (15-17 years old) are kept in the Registry.

The Registry hierarchical configuration includes 3 levels: National, Region, District (lowest administrative unit). In Fig. 1 one can see the link between all levels of the Registry.

The District is a basis for the National Registry. The scheme of performing of physical examination of patients at the District levels shown in Fig. 2. One of the main step of this examination is an "Endocrinologist's investigation". At present time the task of collecting of clinical and laboratory data (blood count, concentration of hormones, etc) has been

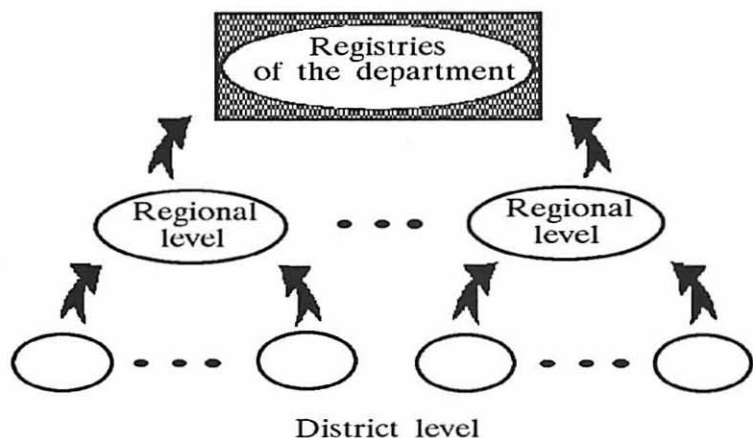


Fig. 1. Hierarchical configuration of links of the National Registry of persons exposed to radiation as a result of the Chernobyl accident

Scheme of the Examination at the District Level

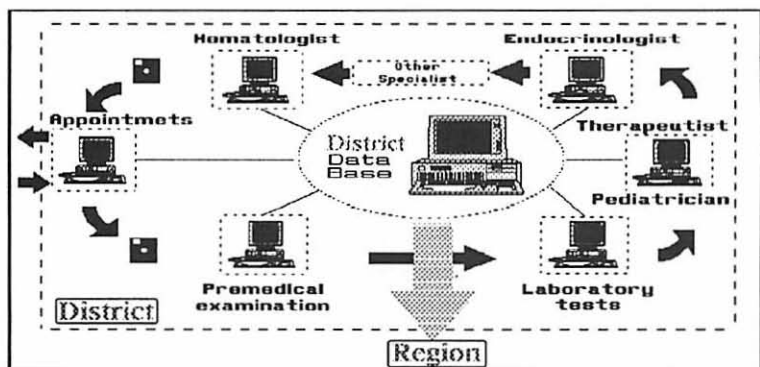


Fig. 2. Diagram of the monitoring of persons exposed to radiation as a result of CPP accident. (District level).

solved. But up to now the operative system for collecting, processing and keeping of ultrasound images of thyroid in children exposed to radiation as a result of the Chernobyl accident has not been developed yet. For these purposes we propose to use the method elaborated by our group. Proposed approach allows to carry out early recognition of abnormalities in thyroid of children. Investigation on influence of dose the incidence of abnormalities observed in thyroid of individuals suffered as a result of the Chernobyl accident allows to recognize pre-cancer state in children.

The present paper deals with the developed method of processing and archiving of ultrasound images and means of its implementation are discussed.

II. STRUCTURAL LINKS BETWEEN VARIOUS LEVELS OF THE NATIONAL REGISTRY NECESSARY FOR PROCESSING AND ARCHIVING OF ULTRASOUND IMAGES OF CHILDREN THYROID

One of the most suitable technique of the non-invasive examination of thyroid is US-scanning. This method does not cause the additional irradiation of the body. However the used US-scanners have some deficiencies, such as:

- images obtained are not enough distinct
- it is impossible to reconstitute the same conditions for obtaining pictures of the same site of thyroid at different time of registration and, as a result, to recognize changes in thyroid.

We suggest that collection of information on the state of thyroid of children exposed as a result of the Chernobyl accident should be structured hierarchically.

The scheme of collecting, processing and archiving of ultrasound images of children thyroid is in Fig. 3.

One can see that there are three main levels of a procedure of collecting, processing, analysis and archiving of ultrasound images. The first level is "District". The main aim at this level is permanent monitoring of thyroid status in children and transferring data to the "Region" level. The main object of the second "Region" level is examination of children with suspicion to abnormal formation in thyroid. At this level collecting and accumulating of information transferred from District level as well transmitting information to the National level is carried out. The highest level is "National". The following measures should be taken at this level:

- collecting data from all "Region" levels and their analysis
- maintenance in an actual state the bank of ultrasound images of children thyroid
- processing and analysis of ultrasound images of thyroid
- elaborating of new diagnostic signs as well recommendations on prophylaxis and treatment of exposed children.

We suggest, that transferring information from the "District" level to the "Region" level should be carried out by telephone.

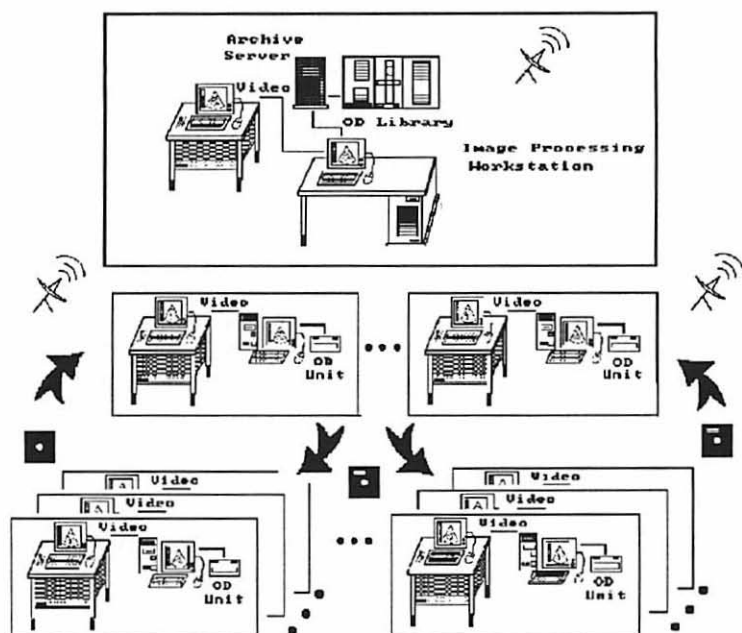


Fig. 3. Scheme of collecting, processing, analysis and archiving of ultrasound images of thyroid of children exposed to radiation as a result of the Chernobyl accident

Since the telephone communication can not provide the high speed and reliability of transferring information without any loss the communication between "Region" and National levels should be carried out by using a satellite.

III. HARDWARE AND SOFTWARE FOR THE SYSTEM OF ANALYSIS AND ARCHIVING OF ULTRASOUND IMAGES OF THYROID

To solve the problems mentioned above the "District" level should be equipped with:

- ultrasound scanner
- frame grabber (a card which allows to connect ultrasound scanner with PC IBM)
- device for storing information on optical disks (OD)
- IBM compatible PC.

Fig. 3 presents the linkage between all devices mentioned above. Ultrasound image is input in PC IBM through the frame grabbers (this way of input of images has been developed in cooperation with QUEST Automation Ltd. company). The elementary processing and archiving of ultrasound images on OD is performed by using PC. Despite their worse than in other units, price/capacity ratio for accumulating information, OD are more preferable because of they enable long-term storing of records, input/output procedures are performed relatively quickly, OD are compact. We propose to use PC IBM as a control unit because of its wide distribution in this country. Similar systems for collecting and archiving of ultrasound images are being operated ⁶, and PC "Macintosh II" are being used as a control units. In these systems the authors do not consider the possibility of processing of ultrasound images.

Software developed for the "District" level allows to:

- identify changes observed in the same site of thyroid recorded at different time
- retrieve automatically objects
- construct 3D images of thyroid using conventional scanners

To store sonogrammes of thyroid the special software has been developed. It includes the following subsystems:

- data base of ultrasound images
- archiving and storing of ultrasound images of thyroid
- quick retrieval of the sonogrammes of a definite patient
- quick scrolling of thyroid images.

The software and hardware for the "Region" level practically do not differ from that used at the "District" level, but at the "Region" level the system for collecting and processing integrated data transferred from the "District" level is operated. The collector capacity at the "Region" level is larger than at the "District" level.

To analyze and process of ultrasound images the National level is equipped with computer station of high computer power as a directing machine. To store images the JukeBox is used as well. In addition to the the software for the "District" level the following systems have been developed:

- system for automatic understanding of changes in thyroid
- system for morphologic analysis of ultrasound images
- link system for the National Registry.

At present time we about complete developing of software for maintenance database of ultrasound images of thyroid. This software will be used at all levels of the National Registry.

IV. ACKNOWLEDGMENT

The authors acknowledge the financial support of QUEST Automation Ltd. company.

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The Clinical Value of Ultrasonic Tissue Characterization in the Management of Heart Transplant Patients

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Introduction

Up to date echocardiographic diagnosis of cardiac rejection was mainly concerned with the analysis of functional particularly diastolic parameters of the heart. The purpose of the present study was to evaluate the ability of a computer-assisted image processing system using the texture analysis of echocardiograms to detect morphological changes of the myocardium, caused by rejection after heart transplantation. This area of research is based upon the assumption that abnormalities of microscopic structure are reflected in the acoustic properties of the tissue. Approaches that have been utilized for ultrasound tissue characterization include direct visualization of abnormal tissue¹, measurement of tissue acoustic parameters such as attenuation coefficients², and integrated backscatter³; and digital image analysis of two-dimensional echocardiograms⁴. This study wanted to examine whether rejection is associated with an abnormal pattern of echocardiographic texture and whether the evolution of the disease may be recognized by means of quantitative texture analysis.

Methods

Patients

The study group consisted of 23 patients (3 females and 20 males) after orthotopic heart transplantation. Mean patient age was 37.2 ± 9.0 years, ranging from 19 to 48 years. The follow-up period ranged from 3 to 16 months.

Postoperative management

All patients received standard triple-drug immunosuppressive therapy with cyclosporine A, azathioprine, and prednisone. Surveillance of cardiac rejection was based on endomyocardial biopsies, which were performed weekly

during the first postoperative month, every second week for further 2 to 3 months, and biopsy intervals became longer during the later postoperative course. Biopsies were graded according to Billingham's classification.⁵ No evidence of rejection was defined in the absence of cellular infiltrate or myocyte necrosis; mild rejection reflected cellular infiltration without myocyte necrosis; moderate rejection demonstrated cellular infiltration with myocyte necrosis; and severe rejection was accompanied by myocardial hemorrhage.

Standardized echocardiographic examination and image digitization

Echocardiography was performed within 2 hours after endomyocardial biopsy. To achieve maximal intraindividual reproducibility and to enable comparison of serial studies, examination procedure was carefully standardized. Two-dimensional echocardiograms were deduced using an electronical 90 degrees sector scanning system operating at 3,75 MHz. Short axis images were obtained at the midventricular papillary muscle level. Special care was taken that the angle of the interrogating ultrasound wave within the anteroseptal segment was around 90°. We chose always the same adjustment of amplification for a patient that we had chosen the first time. Altogether we carried out 408 echocardiographic examinations in heart transplant patients. At every examination the ECG-triggered enddiastolic image was digitized into a 512 x 512 pixel matrix with eighth bit quantitation of the image processing system.

Endomyocardial biopsy

Usually 5 samples of tissue were taken by endomyocardial biopsy. Endomyocardial biopsy was considered positive when two independent examiners arrived at the same results and when rejection was either moderate or severe.

Texture analysis

The pattern of gray level distribution of an image is called "texture". This texture is an important characteristic for identifying interesting image regions⁶. We defined the spatial distribution of echo amplitudes, which are projected as gray values on the screen as echocardiographic texture. Regions of interest were chosen by using an interactive computer program. These rectangular regions of interest with the standard size of 25 x 25 pixel were placed in the ventricular septum in short axis images. The data from each region of interest were analysed with use of measures related to intensity and distribution of echoamplitudes (gray levels). In the present study four major groups of texture analysis were used: first order histogram, co-occurrence matrix, run length analysis, and power spectrum.

Data analysis - classification

Statistical evaluation of ultrasonic texture image analysis aimed at finding out which combination of texture parameters is necessary and adequate for distinguishing between various histological conditions of the myocardium (rejection, no rejection) after heart transplantation. This problem corresponds to the mathematical problem of classification.

The reduction of 117 initial calculated texture parameters to an adequate number was done by means of a series of discriminance analyses. The aim of parameter selection is to obtain an amount of parameters which is relatively low and in which erroneous classification is relatively rare. Parameters can thus be selected by downwards processing, upwards processing, and by a combination of both processes. After calculating the classification principle ("optimal" texture parameter set), the computer classified the data of the texture analysis of the 408 echocardiograms that were altogether taken in 23 patients. For these 408 texture analyses of echocardiograms sensitivity, specificity, and accuracy of texture analysis were calculated in comparison to endomyocardial biopsy according to the following formulae:

$$\text{Sensitivity} = \text{TP}/(\text{TP} + \text{FN})$$

$$\text{Specificity} = \text{TN}/(\text{FP} + \text{TN})$$

$$\text{Accuracy} = (\text{TP} + \text{TN})/(\text{TP} + \text{FN} + \text{FP} + \text{TN})$$

TP = true-positive, TN = true-negative,

FP = false-positive, FN = false-negative

Results

Echocardiographic texture of the myocardium is significantly changing when rejection is developing. Figure 1 and 2 show the gray level distribution in the region of interest in a representative patient in a phase without rejection and at the time of rejection. For quantification of gray value distribution altogether 117 texture parameters were calculated. The first 131 echocardiographic examinations and the corresponding endomyocardial biopsies were considered the learning class. The myocardial biopsies showed the following results:

no rejection = 54

rejection = 39

fibrosis = 38

The stepwise reduction of the 117 texture parameters with the aim to find an optimal parameter set, was obtained as follows:

1. Already when checking the beat-to-beat variability, the angular second moment had already shown a high variation coefficient. Also, it is closely dependent on the degree of amplification set by the controls of the ultrasonic equipment. For these reasons, this parameter was not considered in further calculation. Thus, there remained only 97 texture parameters.
2. By means of the Friedman's test, the parameters with the lowest distribution differences between the bioptic groups were excluded. The distance at which the criteria were distributed among the groups was measured using the values of Friedmann's test statistics. Thus, the amount of parameters could be reduced to 21.
3. The remaining 21 parameters were subjected to a series of discriminance analyses using upwards and downwards processing.

By means of this discriminance analysis, the parameters sector sum $0-30^\circ$, run length nonuniformity vertical, and inverse difference moment $dx=2$ undirected were found to be sufficient for the separation between "no rejection" and "rejection". After the classification principle (texture parameter set) had been found by discriminance analysis, the parameter set was used to classify all 408 data sets of texture analysis. Sensitivity, specificity, and accuracy of texture analysis in comparison to histological examinations of the myocardium were calculated. The results are presented in Fig. 3. The sensitivity of the computer classification was 89% and the specificity 83,6%.

Single case analyses of courses show that during the time of possible rejection, texture parameters can early indicate tissue change. Therefore, it is very important to follow up the changes of echocardiographic texture after heart transplantation. The postoperative course of a selected patient is presented in Fig. 4. In this patient, the first three bioptic controls were negative and echocardiographic texture, at this point, was normal. On the 31st postoperative day, echocardiographic image texture was changing, whereby, among other changes, there was a decrease in run length non-uniformity. The biopsy, at this point, did not indicate rejection. However, the bioptic control 7 days later showed signs of moderate rejection. The parameter run length uniformity continued to be low. Immunosuppressive therapy was applied. After two weeks, the control examination revealed normal histological conditions. Also, echocardiographic texture was back to normal. During the further postoperative course, texture parameter changes coincided with bioptic findings of rejection.

Discussion

In this study acoustic properties of cardiac allografts were assed by measuring the texture parameters of echocardiograms. In a two-dimensional ultrasound image, the spatial distribution of returning echo signal gives rise to the apparent texture, which results from acoustic speckle. The acoustic

speckle results from constructive and destructive interference of ultrasound reflected from myocardial microstructures. Therefore, the spatial pattern of speckle bears a complex and indirect relation to the specific internal architecture of the myocardium. Altered myocardial texture was described by analysis of two-dimensional echocardiograms in several myocardial diseases. In recent publications, some working groups reported on animal experiments that aimed at recognizing and differentiating rejection by means of echocardiographic tissue characterization. All authors agreed that acute rejection affects a change in the acoustic properties of the myocardium, measured as integrated backscatter or pixel intensity of echocardiograms. The results of the present study suggest that the process of acute cardiac rejection is reflected in typical and reproducible changes of echocardiographic image texture. The texture becomes lighter, more heterogenic and has stronger contrasts. These texture changes of the echocardiographic image could be recognized and quantified by digital image analysis. By application of Fischer's discriminance analysis, a set of 3 texture parameters was selected out of 117 initially calculated parameters that describe echocardiographic image texture during cardiac rejection. Using this set of parameters, it was possible to distinguish rejection from non-rejection.

Although the relationship between echocardiographic image texture and anatomic composition of tissue is complex and has physically not yet been completely understood, we can assume that the processes connected with rejection, such as cellular infiltration, myocytolysis, interstitial edema, and changed perfusion, influence the acoustic properties of the myocardium and with this the echocardiographic image texture. By interstitial edema, the distance between the scatterers is enlarged, i.e. the number of scatterers per volume unit is diminishing. The increased liquid content of the tissue, on the other hand, influences its attenuation qualities, i.e. with increasing water content, there is less attenuation. By cellular infiltration the density and elasticity of the myocardium is affected, which is leading to changed, usually increased reflection. At the same time, size and shape of scatters are changing. Changes of fiber-orientation and rearrangement of dominant myofibrils occur. The edges of myocardial fibrils can disappear as a consequence of cellular infiltration so that the originally heterogenic medium of the myocardium becomes more homogenic. The change in perfusion which accompanies a rejection episode additionally affects transmission and reflection of ultrasound. Using only 3 texture features for classification, a method determined by discriminance analysis, proved highly suitable for revealing acute rejection episodes. It is interesting that each texture parameter originates from a different group of the texture-analytical process, the inverse difference moment from the co-occurrence matrix, the run length nonuniformity from the gray level run length analysis, and the sector sums from the power spectrum.

Conclusion

Summarized we conclude:

- An analysis of gray level distribution (texture analysis) of the echocardiogram allows an assessment of the structural state of the myocardium.
- Acute allograft rejection is reflected in a change of echocardiographic texture.
- Using only a set of three texture parameters (inverse difference moment with the pixel distance 2 undirected, run length nonuniformity vertical and sector sum of the power spectrum), it is possible to distinguish "rejection" from "non-rejection".
- Thus new noninvasive diagnostic possibilities become available in the determination of acute rejection after heart transplantation.

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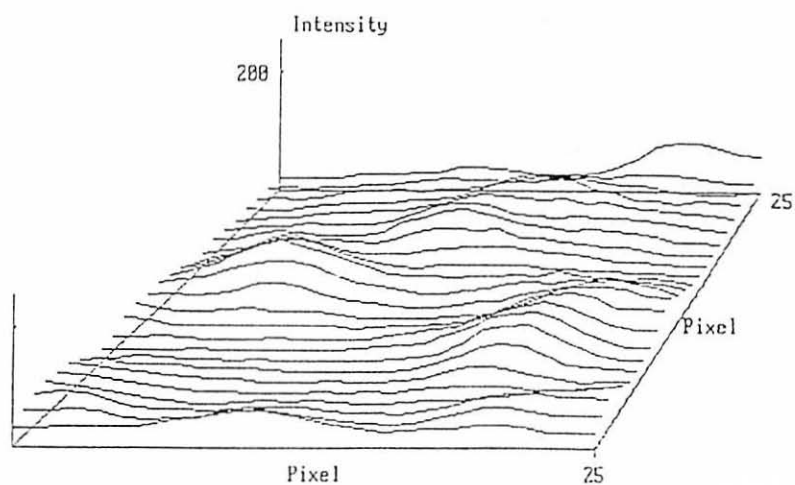


Fig. 1: Gray level distribution without rejection

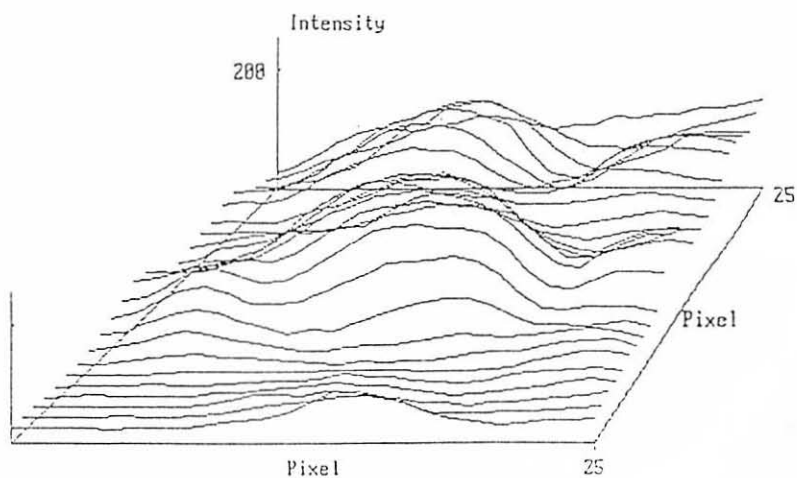


Fig. 2: Gray level distribution at time with rejection

Computerdiagnosis

Biopsydiagnosis

	Rejection	no Rejection
Rejection	75	9
no Rejection	32	272

Sensitivity : 89.0%

Specificity : 83.6%

Accuracy : 85.0%

Fig. 3: Computer assisted diagnosis of rejection

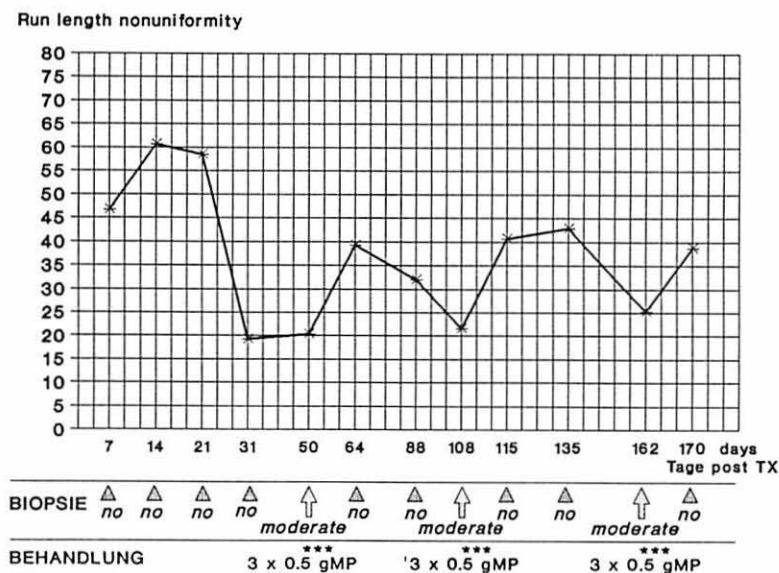


Fig. 4: Postoperative course of a representative patient

SESSION 9

**Picture Archive
and Communication Systems**

Chair: David E. Avrin

A Functional Model for PACS Beyond Radiology

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Introduction

In its simplest form, the process of Radiology imaging is comprised of five steps:

- Ordering a test
- Performing the procedure
- Interpreting the images
- Communicating the results
- Planning the next test or treatment

The preponderance of PACS activity over the years has been aimed at the third phase of this process, interpreting the images. In order for PACS to succeed at primary interpretation, the soft copy workstation must equal or outperform an average \$16,000 film alternator that can display hundreds of CT/MR slices in about 8 seconds. The costs for such a workstation vary widely from \$150,000 to \$500,000 once assembled, and involve expensive leading edge technology for networking, display devices and processors.

Our approach to PACS leaves the interpretation phase untouched and film-based. Instead, we have explored the applications and technology needed for the latter steps in the process: communicating results and planning the next test or treatment. A consultation and review application (C&R) for non-radiologist clinicians is financially and functionally a very attractive starting point for PACS. Bringing images electronically into the operating rooms, inpatient floors, ambulatory clinics, radiology reading rooms and private offices on the medical area campus is a far superior method of communicating diagnostic results than the current method whereby clinicians walk to Radiology and then oscillate between the film library and the reading rooms.

The Evolution of Consultation & Review

We conducted focus group sessions and demonstrations with large and small groups of physicians in Medicine and Surgery who responded to the prototypical display applications with overwhelming enthusiasm. After presentations to the hospital's President, CFO, and clinical Vice Presidents, the administration was receptive and supportive of building a hospital-wide imaging system for consultation & review. There was no objective data on hand. Rather it was the leadership's subjective assessment that the house staff of approximately 1100 physicians would work more efficiently with such an imaging system in place.

Clinicians are familiar with the film paradigm which depicts images at a fixed window and level. Comments from the focus groups indicated that few non-radiologists were interested in modifying the window and level of an image unless there were special settings available for bone and soft tissue. With a diagnostic report at hand, it becomes feasible to lossily compress the image and further reduce the network's burden [see figure 1]. Clinicians were shown images with a 10-15 second response time and found the delay tolerable and far preferable to waiting for elevators and walking to radiology. Early testing indicates that much of the 10-15 second delay may go unnoticed while the physician reads the diagnostic report prior to perusing the images. The presence of a diagnostic report lessens the need for a C&R application to retrieve comparison studies. Viewing stations may use less expensive displays (1K x 1K) and retrieve less than the full dataset even though it is available at full resolution.

There is clear support within Radiology for C&R applications as well. The expected benefits are a decreased demand for film filing in the film library and fewer disruptions in the reading areas. Furthermore, the expectation is that the quality of ad hoc interactions between radiologist and referring physician will improve. Since the requesting physician will have found and viewed in advance the study and interpretation, radiologists will be called upon where their expertise is most valued, that is, for advice and consultation in planning the next test or treatment. A precondition for C&R is the ability to display a preliminary or preferably a final diagnostic report with the images. Given the current state of communications technology and protocols available to radiology information systems, hospital information systems and display devices, this requirement may be achieved easily.

Difficulties with Primary Interpretation PACS

The PACS infrastructure needed for C&R applications is functionally identical to the one needed for softcopy primary interpretation; both need images to be acquired digitally, transferred via a network, indexed in a database, stored in an archive and retrieved for display. The infrastructures are very different however, with respect to scale and throughput and the implementation costs for C&R are far lower than those for primary interpretation because it is less demanding technically.

Primary interpretation requires very expensive, high resolution display monitors (2K x 2K or even 4K x 4K) and full resolution, 16 bit data. The volume of data for a digitized plain film, CT or MR study is conservatively in the range of 8 to 20 megabytes. The network capacity for routine transport of objects this size begins at 100 megabits per second (FDDI) and climbs to SONET speeds of 1 gigabit per second. Though the physical medium (fiber optic, coaxial and copper cable) is the same for all networks, the costs for high speed interface cards and networking components such as hubs, bridges and port concentrators is extraordinarily high when compared to 10 megabit ethernet and 4 or 16 megabit token ring. The image archive is stressed by the requirement to deliver comparison studies for primary interpretation which at least doubles the data volume for the network to transfer. To satisfy this application's appetite for data, the database manager must evolve into an expert system, predicting which images will be needed and pre-positioning them on local magnetic disk sub-systems in the off hours to relieve the network.

Two major expense obstacles to the general proliferation of PACS are the physical plant improvements necessary for a campus-wide network and the optical and magnetic storage for digital archiving. Support from the institution brings a new source of capital and salary funding which eliminates these budgetbusters from the competition with revenue programs for scarce radiology capital resources. Maintenance of the cable plant may be handled chiefly by the hospital's telecommunications staff allowing the PACS staff to target its efforts on the imaging intensive elements of the system. Taken together, a primary interpretation imaging application stretches the commercial technology to its limits, competes unsuccessfully for resources against revenue generating projects, drains the technical staff people who support the system and is itself an unsatisfying alternative to film as characterized by radiologists.

An Environment for Other Applications

By adhering to industry standards and commercial products, this PACS approach has an evolutionary path that leads back to primary interpretation. As modality vendors embrace ACR/NEMA and the soon to be released DICOM version 3.0 specification, image acquisition will be simplified and improved. Digital archives may evolve first from a centralized departmental store of images to a decentralized philosophy that will allow each modality to maintain its own local archive where demand for retrieval is highest. The costs for FDDI networks will decrease and proliferate across hardware platforms as sales increase and as more vendors enter the market. Once the costs are acceptable the conversion from slow speeds to FDDI is relatively uncomplicated, involving the exchange of one set of interfaces for another. It may also be a phased conversion with simultaneous retrieval by devices on either network. Thus, a PACS designed for C&R applications that services the greater medical community may function nicely as a testbed environment. Primary interpretation, electronic teaching files, decision support systems, interesting case libraries or any other secure application can be constructed upon this foundation by advancing the technology selectively.

Value-Added Imaging

It takes a staff radiologist a relatively short period of time to identify a finding and describe it precisely in an interpretation. There is however, an untapped goldmine of information stored in that digital image dataset which is invaluable to the interventionalist who will treat the patient next. We see image processing applications or "value-added imaging" as a new and promising industry that will reveal this information to physicians in ways that never existed before. Three dimensional reconstruction, primary interpretation, tissue segmentation and multi-modality registration are a few examples of potential applications that rely upon the same PACS infrastructure as C&R applications. By providing this new service to clinicians, PACS will become a more essential part of patient care outside of the radiology department and increase the demand for building such a system. If third party payors would consider reimbursing for the value added by these image processing applications, then PACS would become a revenue center.

These image processing applications are very compute-intensive by their nature and exist now almost exclusively as research projects, although some commercial systems are available. Each year the computational power of desktop workstations rises and the system price falls [see figure 2] making it that much easier for value-added imaging applications to migrate into the clinical setting. We envision high powered workstations in the offices and clinics of neurosurgery, general surgery, plastic surgery, radiation oncology, cardiology and neurology once the difficulty of retrieving digital images is removed. We expect these applications to impact PACS performance in a manageable way. The cases to be processed represent a fraction of the entire caseload that is interpreted or retrieved for inquiry, and the timetable for satisfying image processing data requests is measured in days as a preparation for a scheduled test or treatment, much as the film library pulls folders days in advance.

Work and Information Flow In

Figure 3 describes the logical flow of data into the component systems of PACS as defined here. Since modalities and images are so varied, this process depends largely on developing or purchasing an acquisition server, i.e., the function of moving image datasets from the modalities' dedicated scanner-computers through a temporary storage station and then to an optical archive. The acquisition server also acts as a point of demarcation, isolating the proprietary scanner systems and ensuring the integrity of the patient demographic data and image data on its way to the permanent archive. Because of research agreements in place with our scanner vendors, we have begun developing an acquisition server as described below.

Patient studies are first recorded in the radiology information system (RIS) and assigned a unique accession number (ACC#) which will be used as the index to all other textual data associated with the patient and study. The RIS used at Brigham & Women's Hospital is DECrad®, Digital Equipment Corp, Maynard, MA. As the images are acquired, the radiology technologist will enter the patient name, medical record number and ACC# into the series/study header. The acquisition server polls the scanner and automatically copies images from the scanner to a local store. The contents of the header are examined for patient demographics. If no ACC# exists, the study goes on an exceptions list for the chief technologist to review. Over a one month period, the technologists in CT and MR entered the ACC# in 84% of the exams performed without the exceptions list as a feedback system. We expect that compliance will improve substantially once the technologist feedback system is in place.

The acquisition server then queries the RIS and compares the "official" patient demographic data with the header contents. If the RIS is unavailable, the event goes into a retransmit list. If the header and RIS data cannot be reconciled to uniquely identify the study, then the study goes to the exceptions list. Once patient ownership is determined, the study is filed by ACC# on the local store and the server transmits to the RIS the new image status for this ACC#, e.g. "captured". If the RIS is unavailable, the event goes into a retransmit list. The entire study is then copied to the

archive and a new image status is sent to the RIS. Image processing functions such as data reduction, compression, or conversion to ACR/NEMA formats, may be done where and when it is convenient, either on the acquisition server or the archive. If the archive is unavailable, the event goes into a retransmit list. After the archive confirms that the study has been received, the acquisition server will again update the image status in the RIS.

Integrating imaging data into the RIS was more attractive than exporting much of the RIS data to a separate imaging database because we could augment the RIS with some image status and file pointer information far more quickly and easily than we could recreate a new RIS database. It is also important to note that hundreds of employees in Radiology and Medical Records are laboring each day to keep the RIS data very accurate. Based on our experiences exchanging data with the HIS, we found that keeping two dynamic and largely identical databases synchronous at all times is a vexing task. We instead adopted this client-server model where each object (RIS, acquisition server, archive) behaves predictably and communicates with others as clients when asked.

Flow of Information Out

The C&R application proposed in figure 4 takes into consideration the fact that Brigham & Women's is an academic environment, with an abundance of hardware and software platforms that all need access to images. By developing an inhouse application program interface (API), any of the research laboratories in the institution may have access to radiologic images and/or a consultation & review display application. Non-standard methods of communicating are the fastest and easiest to prototype, but are not very flexible. Evolving specifications such as DICOM and HL7 have a high likelihood of becoming universally accepted methods but performance may be an issue along with vendors' willingness to comply. One long term objective is for the API to be able to communicate with any manufacturer's imaging products without developing new software each time a new device is encountered.

Summary

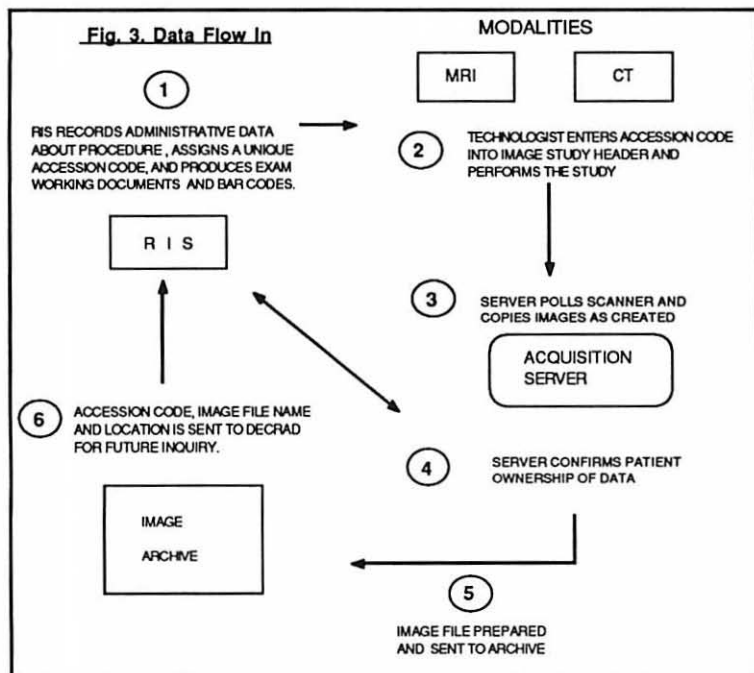
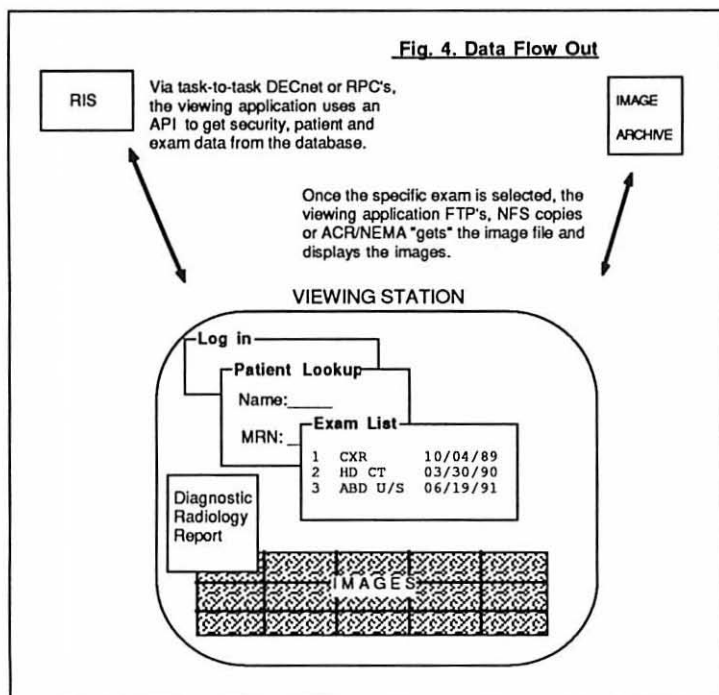
PACS geared towards consultation & review (C&R) has a strong likelihood of attracting adequate funding by providing a new and better service to the the medical community than the traditional film and paper method of communicating diagnostic results. The implementation costs are lower than primary interpretation PACS because the performance requirements are less stringent. Building a PACS is largely an exercise in systems integration, tying together data acquisition, mass archival storage and data management via networks. Once completed, a PACS for C&R may serve as a development and test environment for other applications such as electronic teaching files, primary interpretation or interesting case libraries. Image processing applications that add value to test and treatment planning activities increase the demand for PACS. Over time, the prospect of reimbursement for value-added imaging may transform PACS from an overhead cost to a source of revenue.

Image state	Original	Windowed and leveled	Minified	Losslessly compressed	Lossily compressed
Ratio	1:1	2:1	16:1	2:1	25:1
Resolution	12 bits	8 bits	8 bits	8 bits	8 bits
Size	20 MB	10 MB	0.63 MB	0.31 MB	25 KB

Fig 1. A data reduction table showing the diminished workload for slow speed networks. Compression algorithms being evaluated are fractal image format (FIF), JPEG, Huffman, Lempel-Ziv and BWH proprietary techniques. Minified images are a 128 matrix from a 512 matrix.

	19 92		19 91		19 90	
	MIPS	Cost / MIPS	MIPS	Cost / MIPS	MIPS	Cost / MIPS
Sun SPARC	27.5	\$364	16	\$1,563	12.5	\$2,000
DECstation	25	\$428	12	\$1,042	8	\$2,563
VAX 6000	7	\$20,357	3.8	\$52,632	3.8	\$72,368
DEC ALPHA	300	\$47				

Fig. 2. Comparison of declining computational costs for different computer systems. A similar advantage in price and performance for disk and tape subsystems is not considered here. MIPS is Million Instructions Per Second.

Fig. 3. Data Flow In**Fig. 4. Data Flow Out**

A Simple Distributed Environment for PACS Image Archive Management

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Introduction

A key component in any picture archive and communication system (PACS) is the image archive. Image archive management software provides four basic functions. The archive manager must receive images from the image generating devices, store these images on the archive medium, and maintain a catalog of these images. It must also respond to user requests for images by retrieving the requested images and delivering them to the user in an appropriate fashion.

Three paradigms can describe archive systems: centralized, decentralized, and distributed. A centralized archive uses one monolithic system to perform all of the functions of the archive. Houtekamer, et. al. [1] recently described a system of this type, which tends to be very expensive. In addition, centralized archives must be designed for ultimate desired performance, since the upgrade path usually requires significant capital outlay for larger mainframes. Similarly, it can be expensive and technically challenging to incrementally add new technologies.

A decentralized archive uses the mass storage available on newer image generating devices to archive the studies produced on these devices. This approach is typically feasible only in a homogeneous imaging environment where all devices are supplied by one manufacturer. In a heterogeneous environment, file format and communication incompatibilities complicate overall database management. A decentralized archive transforms the imaging device from an image source to an image source and archive. This added computing burden can be difficult to support considering the real time imaging load already placed on the system. This type of archive requires management of different types of hardware and media and multiplicity of archive support functions such as media management and storage. It also multiplies maintenance requirements.

Houtekamer, et. al. also allude to a third type of archive, the distributed archive. In this model, archive processing and management are shared by several host computers. Physically, the machines can be located in one place to facilitate maintenance and support. Logically, the archive appears to the network as one device. Only within the archive are processing and storage distributed.

Centralized archive management is commercially available, though it is typically expensive and vendor-specific. Decentralized archive systems are

supplied with most newer imaging devices.

An attractive alternative is to custom assemble a distributed archive management system using off-the-shelf hardware and software components. This is possible because of recent improvements in network availability, desktop workstation performance, and operating system functionality in a networked environment. Equally important are advances in client - server computing and large, distributed databases using Structured Query Language (SQL). The increasing use of standards for communication, including the ACR-NEMA Standard for Digital Imaging and Communications [2], has also aided this effort.

By exploiting these developments, an archive manager can yield significant savings and allow incremental growth as other components of the PACS expand. Single vendor dependence can be avoided by using industry standard hardware and software components. Custom assembly of components also provides greater flexibility in defining the behavior of the software than with an external (vendor) specification.

Network connections, especially Ethernet, are now almost universally available. Though inadequate for widespread dissemination of image information due to low bandwidth, Ethernet is sufficient for transfer of the images from image generating devices to an archive where faster redistribution can be implemented. Due to the lengthy development cycle of imaging equipment, it is unlikely that faster network interfaces will appear in the immediate future.

Workstation dissemination in the workplace has been the driving force behind this network proliferation. Alone, or in combination over a network, these machines can provide adequate computing power for an archive application. The operating systems of these computers take advantage of the network configuration. Network computing facilitates incremental expansion, modularity, and sharing of resources. Archive management can exploit these features.

This computing power, tightly coupled to network functionality, allows the development of large client-server computing systems. In client-server computing, a powerful machine with abundant resources (e.g., compute power, memory, disk) provides a service for a less endowed client that exploits the service over the network. Client-server systems include network transparent windowing systems such as X11 [3] from the Massachusetts Institute of Technology, and relational database management systems, such as Ingres (ASK/Ingres Corporation, Alameda, CA). In a windowing system, the client-server protocol specifies graphical information. In a database application, the protocol specifies SQL-based requests and the appropriate replies.

The ACR-NEMA standard also uses the client-server model. This simplifies the transmission of image data from imaging equipment to other computers. Until recently, each manufacturer stored images in proprietary format. Typically, minimal access to the image data was provided through industry-standard nine-track magnetic tape or proprietary mass storage. Even in the evolving ACR-NEMA standard there are discrepancies in implementation among different manufacturers. Commercial ACR-NEMA software exists, however, to shield applications from fluctuations in the standard and in vendor implementations.

The ACR-NEMA standard has been described by Spilker. [4]. Briefly, ACR-NEMA specifies that each image be sent as an individual message. The message consists of groups of information (figure 1). The command group enables the client and server to establish a connection and determine the transaction to take place. The identifying information group identifies the image's place in a study, and the patient information group contains demographic information. The acquisition information group specifies the physical parameters of the data acquisition. Some information in these groups may or may not be present depending on the modality and the manufacturer. The last three information groups contain free text, overlays and the image data itself.

In their extensive review of the PACS literature, Schmiedl and Rowberg [5,6] mention several areas of concern in archive management. This paper discusses these issues in the context of the design of an archive manager. Specifically, it describes the components of the system currently under development at our institution. This software consists of four separate programs which are integrated in a networked environment. PaXman manages the image archive database and presents a graphical user interface for database query and image retrieval. PaXcatcher receives images from the ACR-NEMA software and sends them to the appropriate handling programs, paXadd and paXodd. PaXadd adds the new image to the archive database. PaXodd, currently under development, sends new images to the optical disk subsystem. Figure 2 shows the overall structure of this software system.

Material and Methods

We developed the software using the C language on a Sun Sparcstation 2 workstation with 64 megabytes of memory and 1.4 gigabytes of disk space (Sun Microsystems, Inc., Mountain View, CA). The workstation is connected to other machines by a standard Ethernet network. We used the SunOS operating system (version 4.1.1), a variant of UNIX. All graphical user interfaces were written using Sun's OpenWindows, a flavor of the X11 (MIT, Cambridge, MA) network transparent windowing system.

MergeCOM (Merge Technologies, Milwaukee, WI) software provides client-server support for ACR-NEMA communications. Image generating devices run client programs which initiate requests for service (e.g. sending an image), and the server responds by accepting the images. Our implementation of the MergeCOM server, paXcatcher, receives the images, writes them to a temporary disk storage area, and notifies the other programs.

As an independent program, paxCatcher can run on any machine on the network and communicate with other programs using the network. Similarly, each of the other programs, paXman, paXadd, and paXodd, can be distributed to other machines. A shared file system, a feature of SunOS, allows network transparent sharing of the actual image files by the several programs. All image transfers between clients and servers are performed in accordance with the ACR-NEMA Standard for Digital Imaging and Communication, which requires that each image be sent as a separate message.

Ingres, a relational database management system (DBMS) with a

Structured Query Language (SQL) interface provides data management functions for paXman and paXadd. Its C language interface allows data manipulation from within user programs, while management of the database itself is performed by Ingres. Ingres also provides network transparency for distributing the database on multiple machines.

Database Design

All of the information groups for each image will be stored on the optical disk subsystem. All of the information, with the exception of the command, text, overlay and image groups is stored on magnetic disk, in the archive manager database (figure 1). The command group is unneeded once the transaction between the client and server has been completed. Similarly, the text, overlay and image groups, which constitute the bulk of the information, are not stored in the database as they do not contain information that can be searched.

Images are organized hierarchically, as recommended by the ACR-NEMA standard. Each image is uniquely identified by six pieces of information, the first three of which are: the *station identifier* of the client that generated the image, the *study date*, and the *study number*. Within a study there may be many series of data acquisitions each of which may generate many images. The last three pieces of identifying information are, therefore, the *series number*, the *acquisition number* and the *image number*.

Information in relational database management systems (DBMS) is represented by tables. The database tables, in this case, reflect both the hierarchical structure of the image identification and the separation of image information into groups. There is one table for each information group in the database, as well as one table for each level of the image identification hierarchy (figure 3).

Rather than code duplicate patient information into the study table, there are pointers in the study table to the appropriate entries in a separate demographics table. This level of indirection economizes space in the study table and eventually will allow synchronization of the demographics table with similar information in the radiology information system and the hospital information system.

The study table contains one row for each study in the archive. The DBMS assigns a unique key to each study. This key is stored as eight bytes, allowing for over 10^8 different studies to be identified by the manager. About 85 bytes is stored for each entry in the study table.

In an analogous fashion, the series table contains information for every series in every study, and each series has a unique key. This pattern is repeated in the acquisition table and the image table. The image key in the image table serves as a pointer to the physical information tables (e.g. acquisition parameters, relationship information) that accompany each image (figure 3). This image key, and therefore all information related to an image, is rapidly accessible in routine searches due to the hierarchical structure of the tables. When more detailed searches are required, the physical information tables can be searched directly. The image table also contains a pointer to the corresponding ACR-NEMA message on the optical disk.

User Interface Design

PaXman responds to user requests for images through two user interfaces: an X11-compliant window interface, and an ASCII-based SQL interpreter. The X11 window interface is the primary method of access for radiologists and researchers. This window presents the user with a simple interface for performing complex searches. It does not require any prior knowledge of database management systems. The user may define a search based on any combination of four factors: name, hospital number, modality, and study date and time.

The name function uses the patient name to extract the patient key from the demographics table. Using this key, it finds the appropriate studies in the study table that match the other search criteria. The hospital number function works in a similar fashion. If both fields are left empty then all patient studies matching the other specified criteria are identified.

The user may restrict the search to any combination of the seven imaging modalities defined by the ACR-NEMA standard. Modality restriction, combined with the name/number search, allows the user to ignore studies not of immediate interest.

There are three ways to specify a date restriction: most recent study, studies from a specific range of dates, and no date restriction (i.e., studies from all dates). The specific date restriction allows the user to specify either an absolute date, an interval of time in the past, or six recent past intervals (this morning, this afternoon, today, this week, this month, and this year).

Using these four factors, the user can generate complex searches quickly, then download a study or part of a study to his or her workstation. The images are delivered in ACR-NEMA format. Software is available to translate the images to other common computer image formats.

The user can also query the archive manager through a simple, ASCII-based, SQL interface. With this interface, a user with knowledge of the SQL command language can search and retrieve all of the image and parameter information in the database. Most of the parameter data is optional in the ACR-NEMA standard, and therefore not required to be provided by the manufacturer.

Optical Disk (OD) Interface Design

Optical disks are appropriate for medical image archives [5,6]. Detailed knowledge of the optical disk hardware is not necessary for the design of the archive manager. Only the file system for the optical medium must be specified. The optical file system should have transparent access from the host computer and be distributed among multiple volumes (i.e., individual disks).

In a single volume optical disk application, meta-information stored on each disk organizes bits of data on the physical disk into a directory of file structures. Each disk must therefore be consulted before an individual file can be found. In a multi-volume archive, it would be impractical to consult each volume for this directory information. The meta-information for the entire optical disk archive will be stored on traditional magnetic disks, which are inexpensive, provide rapid access, and are available in sizes up to several gigabytes. Commercial software that

manages the meta-information appropriately is available from several vendors.

Discussion

Network Resources

Four resources are critical to a networked computing environment: compute power, memory, disk space and access, and network bandwidth. The first three of these are directly related to archive management.

Increased compute power, to respond to increased demand for archive management services, can be added incrementally in the form of additional computers or host processors. Additional computers on the network relieve overburdened machines of their pending workload. Multiple processors in an individual host exploit process-level distributed operating systems to increase throughput. The price/performance ratio of these distributed multiprocessing systems remains competitive.

Memory shortages can be managed in two ways. One option is to add more physical memory to the system. The price of memory is dropping and is currently about fifty dollars per megabyte. In a virtual operating system, such as Unix, more reserved disk space may be used as if it were memory. A balance between cost and performance can usually be achieved.

Another important consideration is disk input and output performance. Archive query and retrieval function can be distributed at the hardware/operating system level as discussed above, but if all database tables exist on one machine, that system may become swamped with database disk access requests. To avoid this bottleneck, many commercial database management systems, including Ingres, allow distribution of the database to different machines. One possible configuration for a PACS archive would be to use seven machines for the seven ACR-NEMA specified modalities.

Magnetic disk space for database and meta-information storage can be expanded as needed. The cost of magnetic disks has decreased sharply in recent years. A single desktop workstation might have ten gigabytes of magnetic disk storage, while large database servers can have several tens of gigabytes of disk space.

Network Services

Security, reliability, redundancy and maintenance are also pertinent to archive management. Security, though never absolute, can be based on level-of-threat and a layered defense.

It is possible to isolate networked machines by placing them behind gateway systems. Machine to machine access also can be controlled. Network based authentication systems, such as Kerberos [7], can be added to verify user and machine identity.

The operating system provides the next layer of defense. Security in complex operating systems, such as UNIX, has greatly improved. Most multi-tasking operating systems provide user identification and file protection features. These can be expanded to achieve military quality security.

Lastly, there is application level security. Most large relational

database systems furnish hierarchical security mechanisms that allow individual privileges to be granted based on user name, group or role.

All of these features can be added incrementally as need arises. A combination of these features will provide adequate security for most archive systems. Individual sites must balance the performance and management overhead with the level-of-threat.

Reliability, like security, of a such complex systems is never complete. Redundancy, therefore, is a critical part of system design. Network management utilities can often detect machine crises as they arise. In a distributed environment with homogeneous hardware and software, healthy machines can assume the workload while other machines are repaired or replaced. Low level disk mirroring, where information is simultaneously written to more than one physical disk, helps to avoid catastrophic data loss. Backup tapes, made according to a strict schedule, also can be used to replace inadvertently lost data.

At a software level, server programs, such as the paXman servers, generate error logs that aid in detecting and correcting problems. Database management systems also provide redundancy features such as checkpointing, transaction locking and journaling. Report generation tools, included in the database management system, permit the creation of reports that summarize statistical information used to monitor the state of the database. These reports and logs coupled to notification systems, such as electronic mail, provide adequate redundancy when combined with appropriate hardware measures.

Conclusion

Recent improvements in network availability, desktop workstation performance, and operating system functionality in a networked environment allow individual groups to custom assemble powerful software and hardware systems for a variety of tasks. By exploiting these developments, in , for example, an archive manager, one can obtain a high performance system at significant savings. Such a system provides vendor-independence while allowing for incremental growth. Customization and fulfillment of local demands for software functionality insure ease of use of the application.

Using this approach, we have created a distributed archive manager for a mini-PACS currently under development within our department of radiology. This archive manager consists of four software components: a user interface manager, an ACR-NEMA interface, a program to update the database and a soon-to-be-implemented optical disk interface. Each component is independent of the others and can execute on a different machine. Distribution of the computing tasks can be made at the hardware/operating system level, the process level and at the application level. The components share a common database that also can be distributed to several machines. The simple user interface allows complex searches for image studies while isolating the user from the complexities of the system. This software system will handle our current archive needs and allow for future growth with the developing PACS network.

Figure 1.
ACR-NEMA Message



Figure 2.

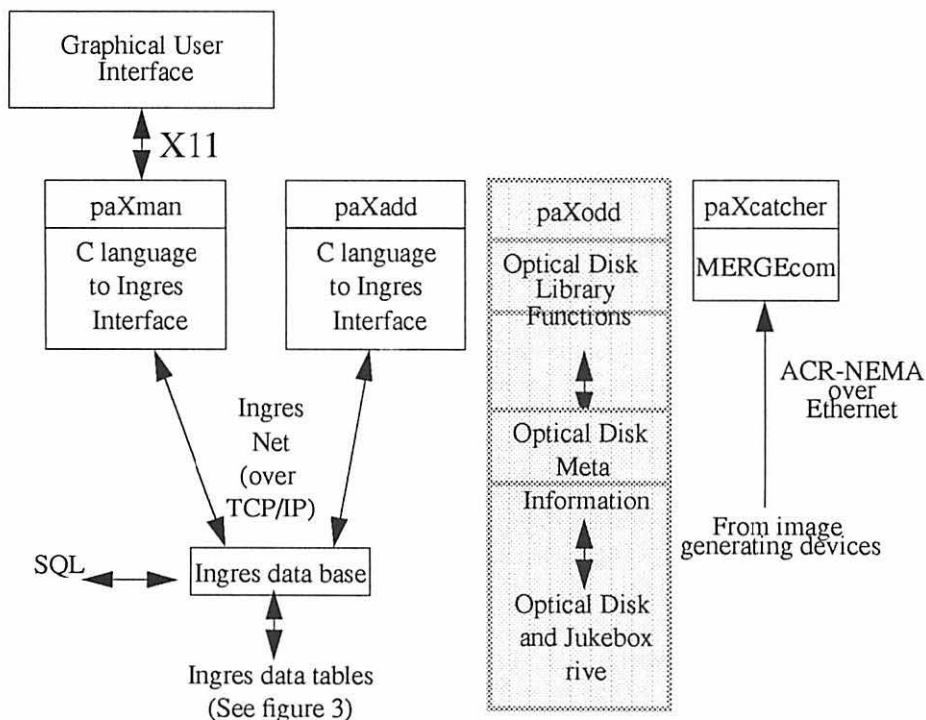
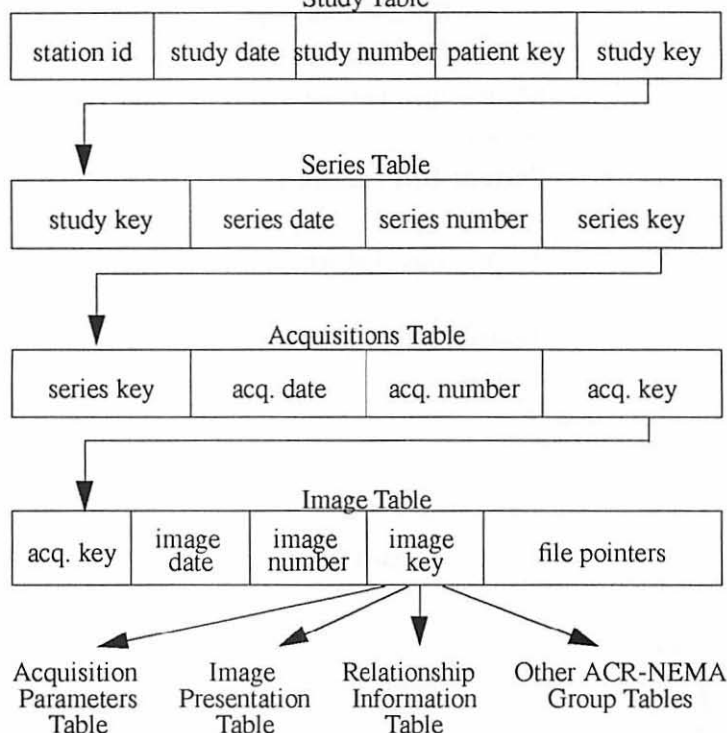


Figure 3.
Study Table



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PACS at the University Hospital of Lille

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Abstract :

This paper describes the structure and objectives of the MEDIMAGE PACS in Lille. The PACS development at the University Hospital in Lille (one of the largest in Europe) has been established jointly by the departments of Radiologie-Ouest (LTNIM), of Computer Sciences, of Biomedical Engineering, the research centre of Medical informatics (CERIM) and the Research Centre Henri Tudor of Luxembourg (CRP-HT).

The geographical distribution of the different radiological modalities (6 Radiological departments in the hospital) leads to PACS.

Our strategic choice is based on informatics standards : UNIX, Xwindow, Motif, Object Oriented (C++), TCP/IP, FDDI and ACR-NEMA.

Our laboratory works on ergonomics of the medical workstation, standard assessment, network, database, data compression and HIS-RIS-PACS interface. The text presents a new graphical user oriented man-machine interface for the medical workstation.

1) INTRODUCTION

The University Hospital of Lille regroups 100 departments spread over 11 buildings. Its capacity is about 4000 beds. In 1990, it decided to build a Hospital Information System in collaboration with the DEC company. In the same time, our laboratory started working on a experimental PACS project to find a solution to the geographical dispatching of the different radiological modalities between different buildings (see figure 1) in the hospital city. This project has two phases. The first one is experimental, and concerns one radiological and 2 clinical departments. Depending on the results of this phase, the project will go on with clinical implementation in the whole University Hospital of Lille.

To build this PACS project, we decided to create a multidisciplinary team, composed by the departments of Radiologie-Ouest, of Computer Sciences and of Biomedical Engineering and the research centre of Medical informatics. We also established a collaboration with the Research Centre Henri Tudor of Luxembourg.

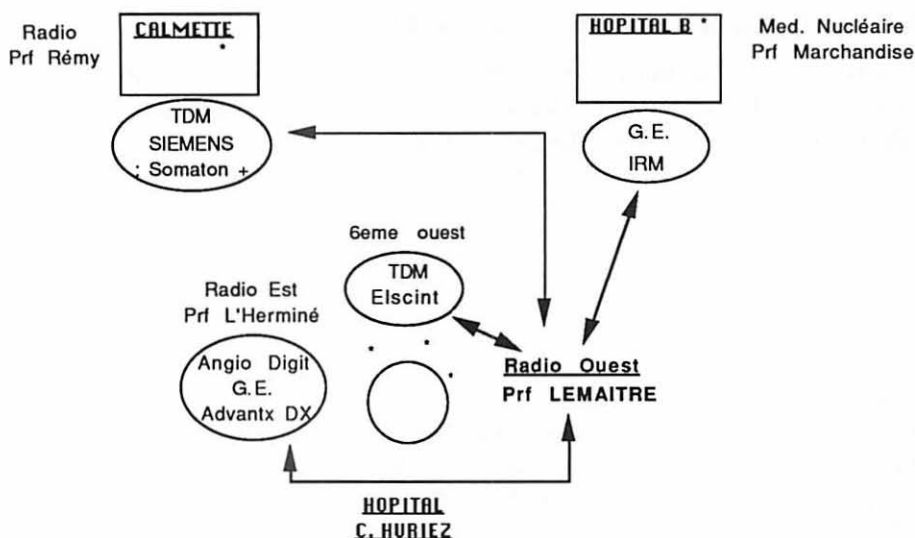


Figure 1

II) STRUCTURE AND AIM OF THIS PROJECT

Two phases have been clearly distinguished for the realization of this project.

- The experimental phase: composed of 8 modules, it will last 5 years (1996).

Module 1 concerns a connection from a modality to the network (4 modalities must be connected to the network)

Module 2 concerns the elaboration of the radiological workstation

Module 3 concerns the data representation

Module 4 concerns the clinical evaluation of irreversible compression and its implementation in the PACS

Module 5 concerns the data storage

Module 6 concerns the implementation of medical imaging in the patient medical record of the HIS

Module 7 concerns the multimedia aspect in clinical practice.

Module 8 concerns the creation and clinical experimentation of a Radiological Summary Record (RSR)

In this experimental phase just concerned one radiological and two clinical departements are for financial reasons.

- The clinical implementation phase: at the end of experimental phase, the feasibility of the PACS will be determined from the results of the different tasks. The

multidisciplinary team and the administration will decide if the clinical implementation phase can start.

Strategic choice.

We decided to build our strategic choices on informatic standards : UNIX, Xwindow, Motif, Object Oriented (C++), TCP/IP, FDDI and ACR-NEMA 2.0 . Indeed, the Information System of the University Hospital uses a mainframe, DEC-PC terminals, Macintosh and Unix stations. The communication of data between these different computer operating systems is only possible if standards are implemented and respected. So the compatibility with the Hospital Information System requires development on Macintosh and PC-Dos.

Architecture of the global CHR network

There are two network types in the Hospital Site: The FDDI Network between the different buildings and Ethernet in every building. There are about 5000t connection points in the network. Every clinical departement has a Unix server, connected on the mainframe and PC-Dos terminals.

Architecture of experimental PACS

The architecture in the radiological departement is very simple. (see figure 2). It is a typical bus architecture network of clinical departement in the hospital. The Digital pictures are sent to the server by the radiologist who examines the patient.

III) STATE OF THE ART OF THIS PROJECT.

Connection with the modalities

Actually the CT Elscint 2400 Elite is connected to the network. We hope to connect the DSA Advantix DX of General Electric within two months and the other modalities within two years.

Data format.

We have developed an object oriented data format, called CHR, based on ACR-NEMA 2.0 (1). We use the object oriented programming C++ language. This data format is implemented on DECstation and PC-Dos.

Data translation

A file translator is working in background on the DECstation. When the data arrives on this station, it is converted in an automatic way into the CHR format. 4 formats are actually translated : Elscint 2400 Elite (CT), Advantix DX of G.E. (DSA), DRS of

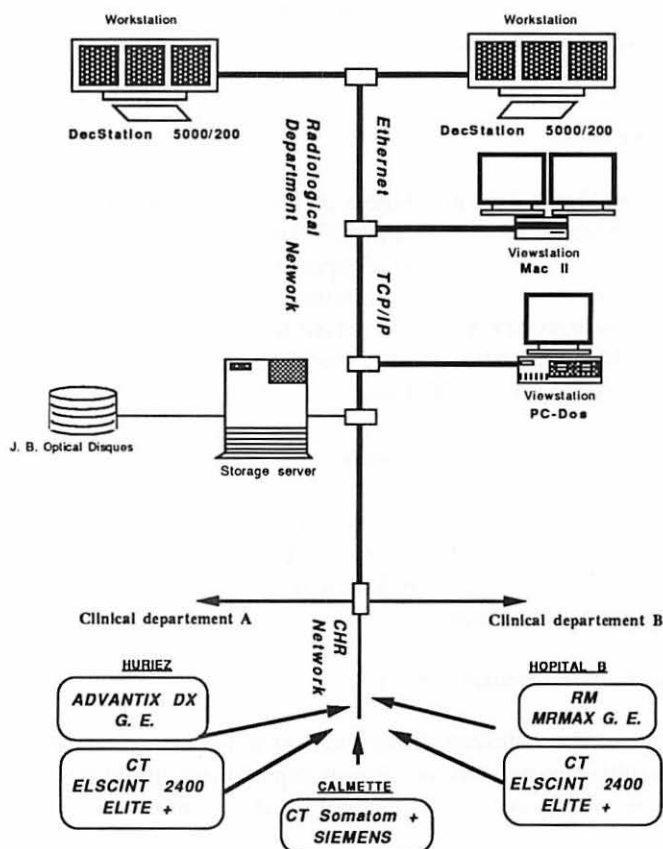


Figure 2

G.E, Somatom + of Siemens.

We developed this translator in C++. It is linked to the data base by specific functions. When a new modality is connected, a new class (which contains the modality format) is created and associated with the member functions.

Data Base

For our experimentation, we developed in C++ a small data base built on ACR-NEMA 2.0. This data base can implemented very easily in any DBMS.

Man-Computer Interface

The Man-Computer interface is based on Xwindow (2) and OSF Motif (3). We used a user interface building tool : DEC VUIT (Visual User Interface Tool).

It contains the Motif and Xwindow tools and generates the UIL language.

Image compression.

Actually, Image compression is based on DCT (4)(5). Some radiologists and physicians are evaluating this compression.

IV) THE RADIOLOGIST WORKSTATION

The radiologist workstation is very important in the PACS. Indeed, the physician just uses this tool therefore a good man computer interface is a prime necessity. We used the new concepts of Joelle Coutaz (6). She divided the man computer interface in 6 tasks: user model, task and functions of the application domain, computer functions and objects, interface presentation and evaluation. We applied this concepts to radiology.

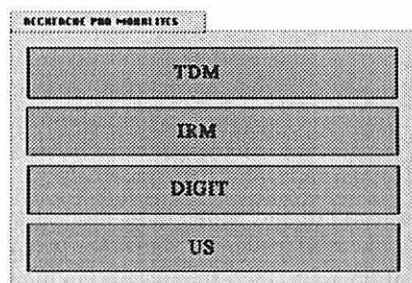
The patient record research

The radiologist accesses to the workstation via his login and password. The "primary" choice is displayed. There are 4 possibilities access: by modality, by identity, in the times and "waiting patient record". Each "primary" choice opens an "secondary"



Primary choice

choice which makes the research. The research approach is summarized in figure 3.



Secondary choice

LISTE PATIENTS						
NOM	PRENOM	NEE/LE	AGE	SEXE	N° DE S. S.	
Dromé	P. D.	10/05/60	31	M	1630559122101	
Dumont	Jacques	20/10/50	33	M	1691234172164	
Dupont	Françoise	03/12/60	11	F	2601262120111	
Durant	Robert	14/02/60	31	M	1600259145125	

Results

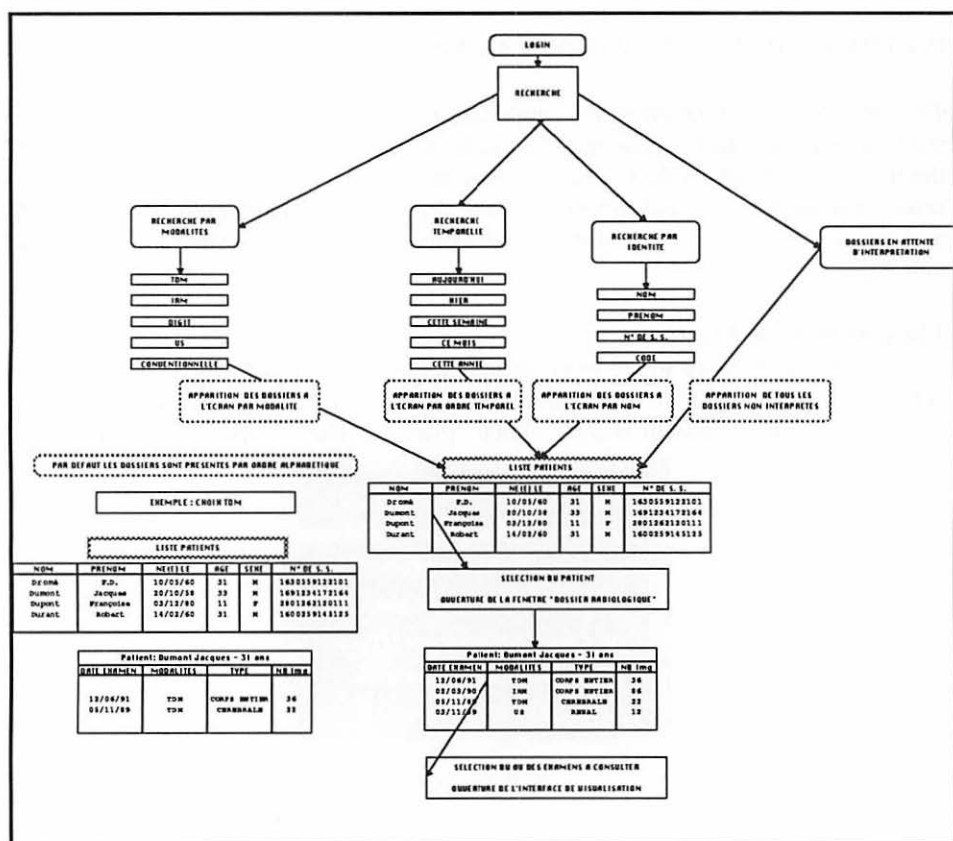
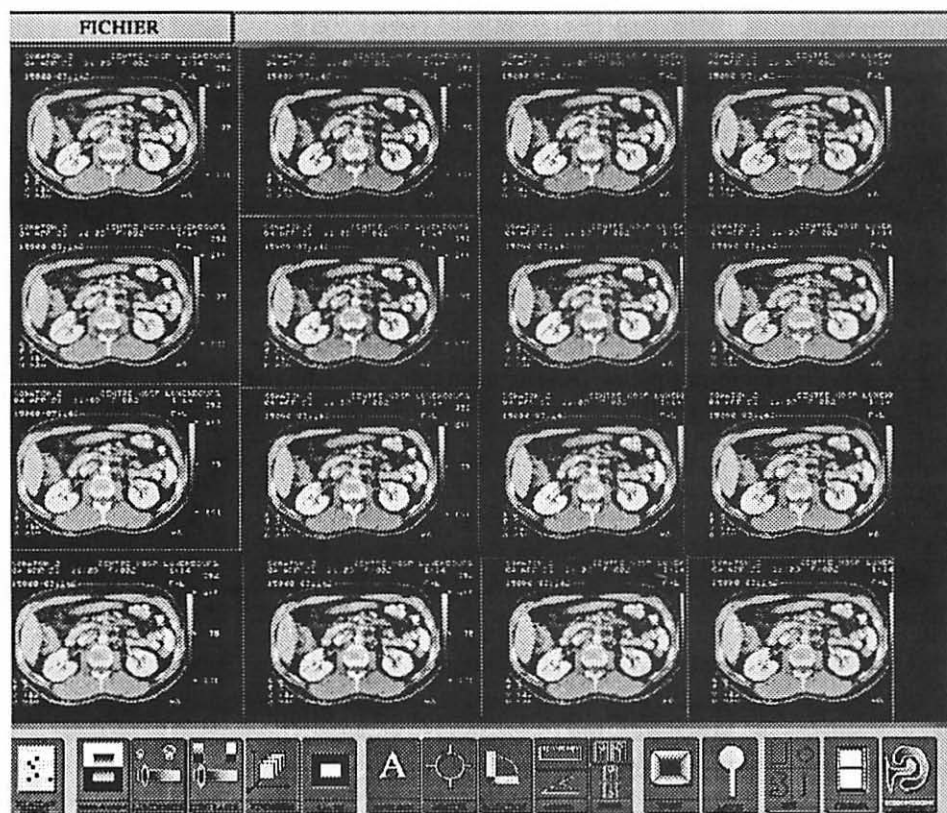


figure 3

Once the query choice made, the viewing interface is loaded and the pictures of the patient record are displayed.

Digital Pictures Display

The picture display depends of the acquisition modality. By default, CT and RM pictures are displayed with 256*256 array. The other (DSA, DX) are displayed at half resolution of the acquisition array. It is summarized in the following board.



Patient record display

Modalités Radiologiques	Taille de chaque images affichées par défaut	Nombre d'images affichable par écran
IRM	256*256	16
TDM	256*256 ou 512*512	16 ou 8
US	1/2 de la matrice d'acquisition	variables
"CONVENTIONNEL"	1/4 de la matrice d'acquisition ou en totalité	variables

Array pictures display

Image processing tools

The mostly used tools have to be present on the screen during diagnosis. They are automatically loaded with the pictures. These tools are represented by icon

Futur perspective.

We are work on the definition of a Radiological Summary Record (RSR). This need has been expressed by the physician of the clinical department. they believe that they are too much pictures in a patient record. This RSR is in study.

V) CONCLUSION

An overview of the state of the art and a man computer interface of the CHRU of Lille has been presented in this paper. Developments are going on and some of our concepts have already been brought to concrete realization in the ergonomic workstation, data format, data base and image compression.

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TeraNet for PACS

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1. ABSTRACT

One of the major challenges in the design of a comprehensive clinically effective Picture Archiving and Communication Systems (PACS) system is the design of the communication subsystem. A PACS performance is closely related to the performance of the underlined network. Due to a large amount of data and quality of service requirements to meet clinical needs, existing networks like Ethernet or Token-ring have not been able to deliver satisfactory performance. Even the newer system like FDDI is limited in its performance as the overall network bandwidth is shared between users and bandwidth control is fairly limited. In order to overcome these difficulties, we are designing a complete PACS based on a novel network known as TeraNet, being developed at Center for Telecommunication Research, Columbia University.

2. INTRODUCTION

A PACS is a computerized system designed to collect data from various sources like MRI, CT, or film digitizer, to transfer the data to a storage system for archiving, and later to distribute to users for display, manipulation and review. Due to an enormous amount of data, the existing networking systems have not been able to provide an optimal solution for a PACS system. For an example, a medium size hospital with four CT and MR scanners, a few film digitizers, and several ultrasound units, must design a PACS which can deal with at least 40 gigabytes of data traffic daily. Also, a clinically viable system must be able to deliver a case study to clinicians within a few seconds consistently. This means that the networking system for a PACS must be able to support several very high speed transmission processes simultaneously without performance degradation under heavy communication load.

Ethernet and Token-ring have been used extensively in designing PACS, due to historical, technical, and financial reasons. However, these networks have not been designed for data intensive medical applications. Ethernet has been designed to support 10 megabits/sec bandwidth, delivering about 400 Kbytes/sec, for business office data communication environments. Due to its collision detection method, Ethernet performs poorly under heavy traffic. Some newer systems use FDDI, which has been designed to support 100 megabits/sec, to overcome some of the problems. However, FDDI does carry similar problems as Ethernet.

In order to design a PACS which can deal with rapidly growing amount of data as well as new computer technology, we need a network which can provide a flexible seamless fast service. In essence, we are interested in a network, which can be considered as an integrated extension to a computer like a disk drive rather than a separate disjointed slow difficult subsystem. After considering many existing systems, we feel that TeraNet may be the best network to use for designing PACS.

In contrast to other high speed lightwave networks, TeraNet can harness the vast bandwidth of optical medium without waiting for a technological breakthrough and provide many interesting possibilities which have not been available to PACS designers.

3. TeraNet

TeraNet is an integrated network designed to provide user access rates as high as one gigabits per second (Gbps), to support imaging, HDTV, computer graphics, video teleconferencing, and other bandwidth intensive applications.

The speed constraints due to digital electronics and electro-optic(E/O) converters have prevented existing networks to utilize the terabits/sec bandwidth of optical media. One way to overcome the constraints is to provide many simultaneously accessible channels within the shared optical transmission medium. One approach to provide message concurrency based on simultaneously accessible channels within the optical medium is through frequency partitioning. Channels in TeraNet are established through the use of Wavelength Division Multiple Access (WDMA) and Subcarrier Frequency Division Multiple Access (SFDMA), which is a two level channel assignment technique which uses multiple subcarrier frequency bands in each laser wavelength. In this scheme, the capacity of a WDMA network is increased by adding multiple microwave subcarrier channels into each optical wavelength band.

In a packet switching network, severe requirements of fast tunability and fast dynamic channel assignment exist, since channel assignment on a packet by packet basis is required for consecutive packets from one source destined to different users. TeraNet overcomes this difficulty by using a multihop design. In the multihop multichannel network, each user is connected to a network access node, which has a small number (N) of transmitters and the same number of receivers, each operating on a preassigned WDMA/SFDMA channel. Each user has a direct connection to only N other users. To reach a destination node that does not have a common channel with the source node, packets are routed through intermediate nodes based on a routing table each node maintains. In a multihop architecture, channel assignment is semi-permanent, permitting logical connectivity to be updated in response to a changing traffic patterns and failure and recovery of nodal transmitters and receivers by modifying the routing tables.

To guarantee the quality of service as negotiated at connection set up, a concept of Asynchronous Time Sharing (ATS) has been used to design

TeraNet. The ATS concept is based on a multiclass network model and asynchronous algorithms for allocating network resources. The Class is specified through delay and loss characteristics, while its attributes are defined by a set of quality of service parameters. The network supports four Classes of traffic. Class C (IV) traffic supports information transfer for network management and control. Class I, II, and III support user traffic. Allocation of communication bandwidth among four Classes is resolved through dynamic scheduling algorithm based on time sharing. Buffers are allocated among the Classes based on space partitioning which is implemented using a specialized hardware architecture. Network traffic monitoring facilities are built into the network hardware to be used by the resource allocation algorithms.

4. DESIGNING AN PACS SYSTEM

TeraNet provides many advantages to PACS designers, like multiple channels within a single optical media, multihop architecture, and excellent network management and control functions.

The multichannel capability of TeraNet provides many direct logical connections using single optical medium, each at data rate as high as one gigabits per second (Gbps). The number of available channels with current technology is about 100 channels of 1 Gbps with a given optical fiber. We expect the number to reach 500, soon. This provides more than enough dedicated 1 Gbps high speed channels for the highly demanding connections like between emergency operating rooms and imaging modalities. The rest of connections can be used to serve other users, who do not require 1 Gbps data access rate. In order to guarantee a high throughput with as many users as possible, TeraNet uses a multihop concept.

By using a multihop multichannel lightwave concept, TeraNet can utilize the huge optical bandwidth efficiently. Every TeraNet node has at least one Network Interface Unit (NIU). Every NIU has two transmitters and two receivers, each set at different combination of optical wavelength and microwave frequency. For any wavelength and microwave frequency combination in the system, there is only one transmitter at one NIU and only one receiver at another NIU. Therefore, the logical topology of the network and its interconnect patterns are easily reconfigured through a proper selection of the microwave frequencies and optical wavelengths, while physical connections are fixed. This is a great help for a PACS designer, since a network can be optimized dynamically, without worrying about physical connections. With other systems, sometimes an additional cabling is the only way to improve the throughput of network, which can be very expensive and time consuming. Also when a building is wired, one only needs to make sure the cable is covering all the space, not what types of equipment will be located where.

For most optical networks, the power budget limitation imposed by the physical optical interconnection topology, which can limit the number of users in the network, is a difficult problem. However, the inherent architecture of a multihop network offers an easy solution by using a concept of optical communities. With optical communities, the network is divided into optical

islands, each supporting a limited number of channels. A user's transmitters and receivers can all be connected to one island only, or to multiple islands, serving as gateways between optical ether communities. In a multihop network, a message may traverse multiple logical links to reach its final destination. The optical community concept provide a simple way of creating semi-isolated efficient work groups, which contain only closely related nodes. Also, it provides an easy method to implement a security system.

The NIU switch are based on the Asynchronous Time Sharing (ATS) concept, supporting a multiclass network model with four Classes of traffic. The concept was optimized for TeraNet to provide high level of flexibility and programmability. Quality of service is controlled in TeraNet with proper transmission scheduling and buffer allocation algorithms, based on constrains related to each Classes like time delay and loss characteristics. This capability provides much needed network priority control functions in designing a PACS. With other existing networks like Ethernet, it is almost impossible to guarantee performance of a particular user session which includes many large data transmissions, due to lack of built-in priority control functions. If two nodes within an Ethernet need to exchange a high volume of data routinely, one may be forced to provide additional network cabling to guarantee the performance, which can be difficult and costly. With TeraNet, a user can request a certain service performance level at the connection time and expect to maintain the performance through out the transaction. Clearly, TeraNet cannot provide every user with 1 Gbps connections all the time. However, it is not difficult provide consistently all the needed users with 200 megabits per second connections and some critical ones with 1 Gbps.

The TeraNet nodes initially will be computers with VME bus. Soon, we will support NIUs for other types of computers. In order to keep the cost down, we are planning to use a general purpose PC-base gateway to transfer data from imaging modalities like CT, MR, Ultrasound, and film digitizer to TeraNet. The PC-based gateway supports Ethernet, video frame grabber, DR11-W, and ACR/NEMA interfaces. The user interface is being designed with UNIX and VMS based workstations using X-windows and IBM compatible PCs using Microsoft Windows. We are currently investigating a possibility of supporting OS 2 also.

5. DISCUSSIONS

We have designed a PACS to support clinical activities as well as research projects. According to our preliminary test results, TeraNet should be able to support each high priority user with 1 Gbps and each low priority user with 200 megabits/sec communication capability, when there are more than 400 active users on the network. With TeraNet, the throughput of network is no longer an important issue in discussing overall throughput of a PACS. In fact, most cases the computers are not fast enough to process data being delivered by the network. In order to make connecting additional medical equipment to TeraNet easy, industry standard protocols like TCP/IP and DICOM are being implemented.

By removing throughput issues related to network, we are now faced with the throughput problems related to permanent global storage devices. The global storage devices like optical juke boxes cannot provide data at network users' data access speed. We are studying possibilities of designing a distributed data storage system based on some newer technologies like 5.25" and 3.5" erasable optical MOS disks. Also, we are planning to support ISAC format for data exchange in future.

Due to high speed of TeraNet, the distinction between network and backplane of a computer is being blurred. From a performance point of view, getting a data from TeraNet may be faster than getting data from a local storage device like a disk. There is a tantalizing possibility of synchronizing many computers on the TeraNet to solve a large problem which each individual computer cannot solve easily with its own resources. In this scheme, it is possible to design a parallel processing system based on networked computers which have excess capacities.

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SESSION 10

**Workstations/Speech Recognition
and Electronic Signature**

Chair: Bob W. Gayler

Electronic Signature of Radiology Reports: A Year's Experience in Streamlining a Radiology Reporting System

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INTRODUCTION:

The Mallinckrodt Institute of Radiology (MIR) has operated a clinical management information system of its own design for many years. As part of a modernizing effort, the opportunity arose to develop an "electronic signature" system for approval of radiology reports at computer terminals. This system has eliminated all intermediate paperwork steps, so that transitions have become instantaneous: reports can be approved as soon as they are transcribed, and distribution copies are printed for mailing, faxed to outside physicians, and electronically transmitted to affiliated hospitals as soon as reports are approved. While the idea of such a system is not novel or unique, this presentation will show our experience with such a system in a large academic radiology department.

SYSTEM DESCRIPTION:

Diagnostic radiology report generation at MIR relies upon an overall network of VAX computers connected by DECNET/Ethernet. Programs controlling this system have been written at MIR in VAX-BASIC, and run under the VMS operating system. The system supports a total of over 300 computer terminals throughout the radiology department. Of these, approximately 30 are situated in the MIR's Transcription area, and dedicated to report processing. Since electronic signature was begun, additional terminals have been installed in MIR's seventeen radiology reading rooms.

MIR produces reports for over 350,000 radiology examinations each year. The report-generation process begins when an examination has been completed and a radiologist dictates a report. Dictation uses equipment and software purchased from Lanier Business Systems. Sixty-four dictation stations are distributed among the reading rooms, sixteen of which are in five adjacent hospital buildings, and the other in a satellite hospital ten miles away. Dictated reports are electronically

queued in the transcription area, located in a building one block from the other hospital buildings. Transcriptionists call dictation from the queue and transcribe (type) preliminary reports into the MIR database. Radiologists then edit these if necessary, and approve (sign) them. Once approved, reports are marked as complete, and final copies are printed and delivered to patients' outside caregivers.

At completion, facsimile (fax) copies of reports are sent automatically to any requesting or referring physician subscribing to that service. Each printed final copy of a report contains a barcode that is swept when the report is handled for distribution. This not only records the "distribution" time for each report, but also confirms that a copy was printed. A list of signed reports without distribution times is printed daily to aid in guaranteeing that all signed reports are distributed.

Before 1991, the report-approval step was done on paper review copies, without computer interaction. After reports were typed, copies printed automatically in the Transcription area. Several times a day, accumulated review copies were distributed to the appropriate reading rooms, where radiologists read them, made revisions, and signed them. Some of these reports could be marked as complete in a batch-mode fashion at a computer station central to the reading rooms. The review copies requiring correction were brought back to the transcriptionists, who entered any changes and marked the reports in the computer as complete. Reports with major alterations required one more trip to the radiologist for final approval. The completion mark triggered printing of the completed copy for outside distribution.

The system for "electronic signature" of radiology reports was developed at MIR and installed early in 1991. Under this system, paper review copies are no longer printed. Instead when a report is transcribed, it is immediately queued electronically for review at a computer terminal. A radiologist then logs onto the signature system with code number and password, chooses a queue of accumulated reports, and edits (if necessary) and signs each report in the queue. Signing simultaneously triggers printing of copies of the completed report in the report distribution area.

Under the former system, a radiologist could page through and review a stack of paper review copies very quickly. We believed that the success of the new system depended on making it similarly easy and quick for radiologists to use.

After a queue is chosen, the first waiting report is immediately displayed. All actions except editing require a single keystroke. If the

report exceeds one screen, the radiologist can scroll forward using the DownArrow key, or page forward using the NextScreen key; and move backward using the UpArrow and PrevScreen keys. The radiologist then has three keystroke options: E, to edit; C (checkoff), to sign; and Q (quit), to skip to the next report without acting on this one. If the choice is to edit, the radiologist then uses the screen editor to make the desired changes, after which a C will sign the modified report. When action on the current report is complete, the next report is displayed without delay, since the program retrieves the next report during the time that the radiologist is reading the current report.

Each preliminary report goes onto multiple queues: one queue for the appropriate reading room, and separate personal queues for each radiologist associated with the report. This gives a radiologist the option of reviewing only his/her own reports, or all reports for a particular service. When a report is signed, it is removed from all queues.

A radiologist file controls other features of the electronic signature system. A bitmap field defines the subset of services for which each radiologist can sign. For example, radiologist A could be given access to the Chest and Body-CT queues, and radiologist B to the Pediatric and Body-CT queues. Radiologists can also be given a subset of viewing, editing, and signing privileges. In this way residents can be given authority only to view and edit reports, while final approval is left to staff radiologists. Finally, if closer control is desired, all of the reports dictated by a radiologist can be restricted, so that only that radiologist can sign them.

RESULTS:

In December of 1990, only two trial reading rooms had been converted to electronic signing. During the first three months of 1991, the other reading rooms were added, so that the new system was in full operation at MIR by April of 1991.

For all examinations, times are electronically recorded for exam completion, report transcription, report approval, and report distribution. It was expected that the electronic signature system would reduce the average typed-to-signed interval, but the results are dramatic nonetheless. Figure 1 shows that this interval has dropped from over 21 hours to a sustained year-long average of approximately 7 hours, a decrease of over 14 hours. Approximately 20,000 reports per month make up the data for each bar in the graph. Reports that have pre-assigned text and require no approval are not included in the data.

For the subset of reports edited before signing, the time savings are even larger. Figure 2 shows a sustained drop from nearly 36 hours to 12 hours or below, a savings of approximately one full day for each edited report.

Figure 3 shows results for one of MIR's busiest sections, the Chest service, where approximately 250 exams are done each day, and where electronic signature was first introduced. Some chest exams began queueing electronically in September, 1990; the rest were added at the end of January, 1991. The average typed-to-signed time dropped from 14.4 hours in August, 1990 to 4.0 hours in March, 1992.

The table in Figure 4 shows that the percentage of reports that are edited increased immediately after the introduction of electronic signature, and has leveled off since. We know anecdotally that to save time under the former system, reports with insignificant errors were often approved without editing. The current increase in edited reports suggests that even minor errors are now being corrected more frequently.

DISCUSSION:

Often in organizations, when improvement is desired in a process, the process itself is not changed, but employees are encouraged to perform their roles more efficiently. If employees receive sufficient ongoing motivation, sustained improvement in the process can occur.

However, in the transition to electronic signature at MIR, the target was the process. With the aid of computer programs, four employee steps were reduced to one. Paper copies are no longer taken to and from the reading rooms, and transcriptionists no longer process the radiologists' handwritten edits and approvals; the radiologists alone now perform the entire edit/approval function.

The sustained steep decreases in average signing time demonstrate not only that the eliminated steps were expendable complications, but also that for the radiologists, the computer signing system successfully replaced the reviewing of paper copies. The 50% increase in edited reports indicates that the most complicated step in the new system, use of the screen editor, has now become a familiar skill.

In addition to substantial savings of time, other benefits have occurred. Greater flexibility and tighter control might seem like conflicting goals for a process, but the electronic signature system provides both. Radiologists now have the flexibility of sitting in one

location and reviewing reports queued for more than one reading room. Moreover, they can do this from any terminal connected to the MIR network. Typically, radiologists sign from computer terminals in the reading rooms, or from personal computers in their offices. Also, approximately 14% of reports are now being signed evenings after 6 PM, and many of these are signed from home via phone modems.

There is greater organizational flexibility as well. Future space allocations can be made with fewer constraints. Since the reporting workload passes between radiologists and transcriptionists electronically, these two staffs need no longer be geographically close to each other. Also, stat reports can now more easily be given special attention. If a report is identified for immediate processing, it can now be transcribed, signed, and printed within minutes of dictation.

The key control enhancement is that reports can no longer be misplaced during processing. Formerly, during their progression from transcription to reading room and back, some copies were inevitably misplaced. A list of reports unsigned for more than 2 days was produced daily, and new review copies of these were printed and sent to the reading rooms. Now as soon as reports are typed, they are in the hands of the radiologists. Unsigned reports do not move; they simply stay on their queues until they are signed, and no employee time is spent dealing with lists of unsigned reports.

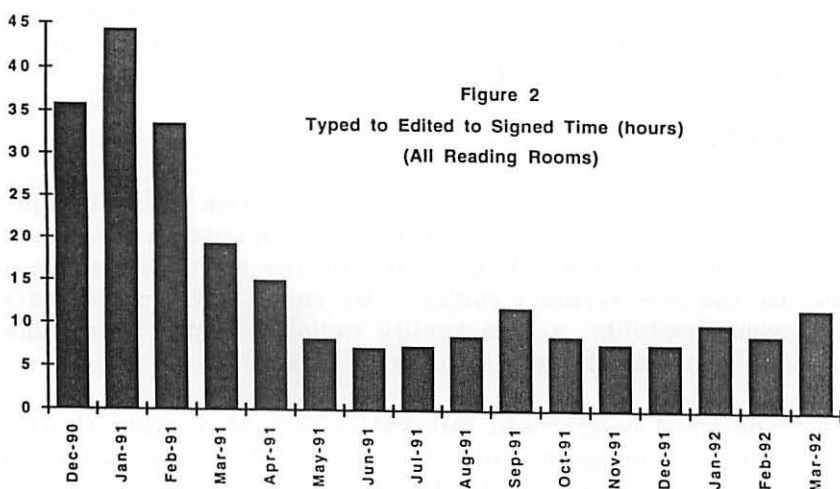
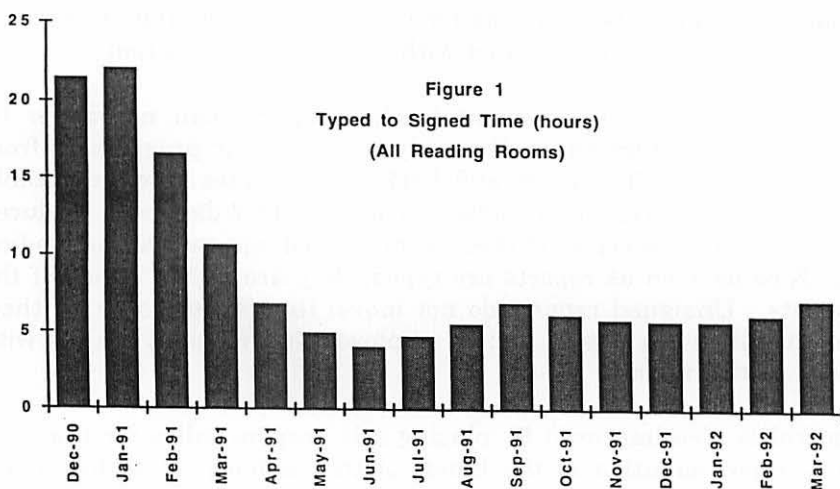
Control is also improved by placing sole responsibility for the final action in report-creation in the hands of the radiologists. This seems appropriate, since they are responsible for the content of the report. The computer now records the identity of the signing radiologist, and prints the his or her initials at the bottom of the finished report. The increase in percentage of edited reports indicates the radiologists' ongoing appreciation of this responsibility.

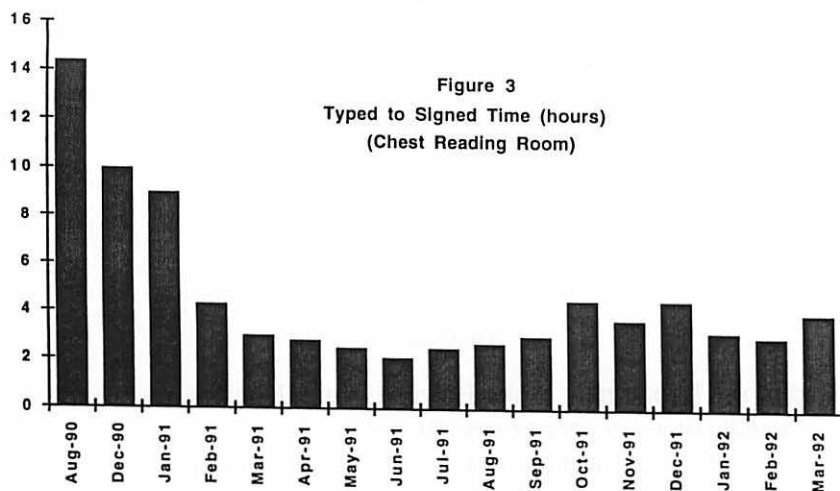
CONCLUSION:

The introduction of the electronic signature system is an attempt to eliminate unnecessary steps and add enhancements in the report-generation process at MIR. A full year's results after its installation demonstrate the new system's success. By virtue of improved control and increased flexibility, a high-quality radiology report is routinely made available in a much-reduced period of time.

The transcribed-to-approved interval is part of a wider timeline, from completion of an exam until distribution of its finished report. This timeline approximates the total time a patient's caregivers must

wait for final results of a radiology exam. For many years at MIR, a desired goal has been to reduce this overall turnaround to a symbolic average of a single day. The installation of the electronic signature system, with its 14-hour reduction in typed-to-signed time, seems to bring MIR within reach of this long-term goal. For the first quarter of 1992, the average time from exam completion until report distribution for all exams at MIR was 24.4 hours. It is hoped that additional improvements along the overall timeline may soon enable MIR to produce finished reports in well below a 24-hour average. Accomplishing this goal for a yearly volume of over 350,000 radiology exams will be a major milestone in providing the best possible medical care to all radiology patients.





	Total Reports	Edited Reports	Ratio
Dec-90	14146	1842	0.130
Jan-91	18424	2250	0.122
Feb-91	16626	2518	0.151
Mar-91	18864	3145	0.167
Apr-91	19186	3764	0.196
May-91	19643	3434	0.175
Jun-91	15760	2748	0.174
Jul-91	18436	3316	0.180
Aug-91	18641	3390	0.182
Sep-91	17503	3016	0.172
Oct-91	21676	4020	0.185
Nov-91	18546	3527	0.190
Dec-91	18262	3161	0.173
Jan-92	20253	3674	0.181
Feb-92	18474	3318	0.180
Mar-92	20897	3947	0.189

Figure 4. Ratio of Edited to Total Reports

In Situ Evaluation of Physician Encounters With a PACS Workstation in a Medical Intensive Care Unit

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Abstract

The Radiology Department at the Hospital of the University of Pennsylvania is conducting a 6-year prospective clinical evaluation of a Picture Archiving and Communication System (PACS) in the Hospital's Medical Intensive Care Unit (MICU). The goal of the study is to evaluate the impact of a PACS workstation on the behavior of MICU physicians. The MICU is a twenty-four bed unit and is staffed by attendings, fellows, residents, interns and externs. After the completion of a radiologic exam, radiographs are processed and immediately digitized and made available on an image display workstation in the MICU. Four display options (zoom, high resolution, inverse, and brightness) are available for use. The number of workstation encounters, as well as use of display options are logged and stored in a database. Usage of these options vary according to the MICU physician category with attendings most likely to use one of these options (42.9%) and interns least likely (28.6%). This paper will describe usage patterns in a live clinical setting, discuss significant differences, and offer potential explanations for these differences.

INTRODUCTION

As the use of Picture Archival and Communication Systems (PACS) increases, it is important to realize that radiologists will not be the exclusive users. While a number of papers have addressed the use of PACS workstations by radiologists,^[1-3] few have evaluated the clinical use of these systems by non-radiologist physicians.^[4-6] It is critical to evaluate the interaction between workstations and referring physicians if, as predicted, PACS is to replace the existing film-based systems and become integrated into day-to-day patient care.

The department of Radiology is conducting a six-year prospective study to evaluate various aspects of PACS. Our work focuses on the image workstation located in the hospital's Medical Intensive Care Unit

(MICU). The MICU is a 24-bed unit whose population is predominantly made up of patients with pulmonary complications. On the average, 13 chest examinations are performed in the MICU daily. The MICU physician staff rotates monthly and includes 2 attending pulmonologists, 1 pulmonary fellow, 2 medical residents, and a combination of 6 interns and externs. In addition to its use by MICU staff, the workstation is also utilized for daily radiology rounds. In the late afternoon, a radiology resident goes to the MICU to review the day's images with the MICU staff. As physicians rotate into the MICU, training sessions are held to ensure that users are familiar with the workstation's functionality. In addition, a research coordinator is on-call and available to answer any questions which may arise regarding the use of the system.

When chest examinations are ordered, the images are acquired using film-screen cassettes. They are then processed, digitized and interpreted in the radiology department. Films are digitized at a 200 micron-spot resolution using a DuPont FD2000 laser digitizer. Therefore, a 14" x 17" sheet of film results in a 1680 x 2048 x 12 bit matrix.

WORKSTATION DESIGN/FUNCTIONALITY

The MICU workstation is configured utilizing two 2,048 x 2,560 Mega Scan monitors for image display and a Sun 19-inch monochrome monitor for text information display. The workstation is based on a Sun 4 platform. The MICU staff routinely provide input regarding the ease of use and functionality of the system and the current design reflects this input.

Prior to availability at the workstation, all images are processed using unsharp masking. These images are generated using a 5 x 5 pixel kernel with a weighting factor of 2.5 in order to leave image contrast relatively unchanged.

In earlier versions of the workstation, clinicians complained about the time needed to load images. With our current hardware, load time was approximately 8-10 seconds. In order to achieve the 2 second load time requested by the MICU physicians, it was decided that, as long as a full resolution image was available (the High Resolution function), the image could be displayed at a lower resolution. Consequently, a 1k x 1k x 12 bit averaged image is created and stored on disk. When a patient's images are selected to be viewed, the 1K image is loaded and zoomed to 2x using pixel replication so that it fills the 2k x 2.5 k image display monitor. The load time for this image is approximately two seconds. While hardware that would allow the loading of the full 2k x 2k image at this speed exists, the cost is prohibitive and we opted for the above solution. The user

interface is completely mouse-driven. By using the mouse, physicians can select several functions which may assist in gaining the desired diagnostic information from the image. The functions are:

1. Zoom- The zoom option allows five steps of magnification progressing to 3x in 0.5x increments using pixel replication. Once "zoomed", the image may be roved by using the mouse to display a particular area.
2. Brightness-The brightness function allows the user to cycle through 23 fixed window/level settings that range over the entire grey-scale spectrum. These window/level settings have been optimized for MICU portable images.
3. Inverse- Inverts the present brightness setting so that bones appear black and lungs appear white.
4. High Resolution (HIRES)- Since the images are averaged and displayed at 1k x 1k, the users are given the option of viewing the image at full resolution. The HIRES option allows the user to view the entire 2k x 2k image. The associated load time is 8-10 seconds.

METHODS

Prior to viewing images, the user is required to select their user category (intern, attending, etc) from a menu . They then select the name of the patient whose image(s) they wish to view. Exams are consolidated under a particular patient name. This decreases the effort on the part of the physician in not having to hunt for exams. A database tracks all information related to this viewing session including all functions utilized.

A link between the PACS and DECrad, the Department's radiology information system, allows other examination related data to be captured and stored in the database. Of particular interest is the clinical history or reason for exam which is provided to the radiology department at the time the examination was scheduled. Using this data, examinations can be separated into various diagnostic categories. The major diagnostic categories in the MICU are: placement or follow-up of tubes and lines, pneumonia, and congestive heart failure (CHF). These three categories account for approximately 40% of all MICU portable chest examinations.

Over the course of an 111 day period, 1,607 chest examinations were performed in the MICU for a daily average of approximately 14 chest examinations. Images from these examinations were made available for viewing on the MICU workstation. These examinations resulted in 3,396 viewings over the same period. 186 exams were never viewed. The utili-

zation ratio, is defined as:

$$\frac{(\text{total \# of exams available for viewing} - \text{\# exams not viewed})}{\text{total \# of exams available for viewing}}$$

The utilization ratio for this period was .89. Based on this definition, the maximum utilization ratio can be 1, i.e. every exam viewed on the workstation.

RESULTS

In the majority of interactions with the workstation (69%), physicians chose to use no image manipulation options whatsoever. When any option was used (see Table 1), attendings were most likely to use them, followed by fellows, residents, interns and radiology residents at conference. Table 1 also provides a breakdown of workstation usage by physician category. Since interns represent the majority of physician staffing and are responsible for the minute-to-minute care of patients in the MICU, they account for the most images viewed on the workstation.

TABLE 1
USAGE OF WORKSTATION AND VIEWING OPTION(S)
BY PHYSICIAN CATEGORY

PHYSICIAN CATEGORY	% USAGE OF WORKSTATION	% USAGE OF ANY OPTION
Attending	10%	43%
Fellow	6%	41%
Resident	26%	33%
Intern	46%	29%
Conference	11%	25%

The pattern seen in option usage is statistically significant in that usage appears to parallel length of clinical experience with attendings having the most experience and interns having the least. Statistical significance at $p=.05$ where the Chi Square value > 9.49 ($df=4$).^[7]

Similarly statistically significant differences were observed when the following options or combinations of options (regardless of order) were chosen: zoom, brightness/ zoom, brightness /inverse, brightness/zoom/inverse, and all options together. Surprisingly, the usage pattern for brightness alone was not statistically significant. It should be noted the viewings of images from each of the diagnostic categories was fairly consistent across user types.

When an option or combination of options was utilized, brightness and

zoom were the two most popular options chosen. However, when viewed in terms of specific diagnostic categories, interesting variations are seen. Of particular note is the use of the inverse function in the viewing of images in the "Tubes & Lines" diagnostic category. When viewed across all diagnostic categories, inverse ranked ninth in degree of usage and accounted for less than one per cent of the options chosen. However, in the tubes and lines category, it accounts for greater than 12% of the options chosen. Table 2 provides a breakdown of options used.

TABLE 2
CHOICE OF OPTIONS IN ORDER OF USE

<i>ALL</i>			<i>TUBES & LINES</i>		<i>PNEUMONIA</i>		<i>CHF</i>	
1.	Br	30%	Br	24%	Zm	38%	Br	35%
2.	Zm	22%	Zm	17%	Br	35%	Zm	35%
3.	Br/Zm	19%	Br/Inv	11%	Br/Zm	7%	Br/Zm	23%
4.	Br/In	9%	In	13%	Br/In	4%	Br/Zm/In	8%

Br=Brightness Zm=Zoom In=Inverse

Usage, in terms of specific diagnostic categories, yielded an additional variation. MICU physicians as a whole chose to use an option 31.4% of the time across all diagnostic categories. However, in examinations that fell into the "Tubes and Lines" diagnostic category, they chose to use one of the options 38.4 % of the time. The "Pneumonia" and "CHF" categories yielded an option choice of 32% and 30% respectively. This represents a statistically significant difference at $p=.05$ tested using the Chi Square statistic.

DISCUSSION

As opposed to many of the other functions, the use of brightness is fairly consistent across all user categories. There are two possible explanations for this occurrence. One is the variability in image quality often associated with portable examinations. Brightness may be used to compensate for either over- or under-penetration. The second is the limited number or grey-scale levels which can be viewed on the monitor at any particular time. One must use the brightness function to window through the entire available grey scale.

The high usage of the "zoom" option is, in all likelihood, related to the relatively small image display area associated with the display. The actual image-display area is approximately a 9"x11" window. The image must be zoomed to display a portion of the image at actual size. The use

of the zoom option followed a similar pattern to that shown in Table 1, with attendings most likely to use zoom and interns least likely. Attendings, having the most clinical experience, have viewed images at "full size" for a much longer period of time. One might infer that interns are more comfortable viewing images at the smaller size because they have less experience viewing radiographs and are not biased toward viewing the "full size" image. Another possible explanation for the increased usage of the zoom function is that clinicians are using it as a surrogate for the HIRES option. In spite of the fact that it yields no increase in spatial resolution, clinicians may feel that it is helpful.

The use of inverse images has been studied and demonstrated useful in the detection of both pulmonary nodules^[8] as well as line and tube tip positions.^[9] Although the accuracy of using the inverse function is beyond the scope of this paper, physicians in a clinical setting would not take the time to use it if they did not feel that it assists them in gaining diagnostic information from the image. *In short, if a function helps, it will be used.*

The use, or more appropriately, the lack of use of the high resolution option is surprising since it has been shown that diagnosis dependent upon the visualization of detail (pneumothorax and interstitial disease) require high resolution.^[10,11] Although it appears that HIRES is used slightly more in the "Tubes and Lines" category, it accounts for less than 5% of the options chosen in this category. The pattern observed for this category appears to indicate that either the physicians do not feel that it assists them gain the desired information from the image, or it is not worth their time to wait the eight to ten second period while the full 2k x 2k image loads from memory.

As was previously stated, use of functions in the "Tubes and Lines" category was greater than the other major diagnostic categories. Perhaps clinicians felt that the use of an option in this category had a greater impact than in the other categories and were therefore able to derive more diagnostic information from the image. This may be partly attributed to the usefulness of the inverse function in determining the position of tubes and line tips.

The low incidence of use of functions in the conference is not surprising. In this setting, the radiologist uses the workstation to review the images with the MICU physicians. Both have more than likely already seen the image and options are used to enhance a specific radiological finding. This differs from the use of the workstation by the MICU physician in that they are often using the workstation for primary diagnosis.

CONCLUSION

While it is critical that we understand how radiologists use image workstations, it is equally important to understand their use by non-radiologist physicians. The MICU workstation is in place and is being used extensively. The usage patterns show differences in utilization of the workstation and of processing options on the basis of experience. They also show that clinicians are willing to trade rapid access for resolution. However, it is not clear if they understand the consequences of the tradeoff in terms of diagnostic accuracy. We are continuing to evaluate the use of the functions in an attempt to understand some of these differences.

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Improved Report Turnaround by Computer-Based Generation and Verification

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INTRODUCTION

In today's service oriented society, radiology is a consultation specialty with service to referring physicians and patients its primary goal. Ideally examination reports are available to the referring clinician within a few hours after completion of the study. Our hospital is a high volume teaching institution, which has utilized multiple forms of computer-based report generation for diagnostic radiology exams. This paper describes several of these methodologies and the effects of their implementation on decreasing report turnaround times. These methods include; a direct on-line generation and verification technique, computer based verification, and digital dictation, in contrast to traditional tape to typist methods with manual editing.

METHODS

The goal was to achieve the generation of verified reports for 85% of all radiology exams within 24 hours of the exam completion. Onsite training was provided for radiologists and a management structure was implemented which facilitated and strongly encouraged their use. Management techniques included the use of a Gantt productivity chart measuring the average reporting time of each radiologist matched to the 24 hour goal, listing the radiologist from best to worst. Also, each modality was measured on a weekly basis, with separate quantification of one day, and over two days turnaround. Usage of the three computer-based systems mentioned above was separately monitored, and the effects of their use assessed.

Time to verification is defined as the time from exam completion to verification, or approval, of the report by the radiologist. This is considered the time at which the report is available for the referring physician. Data were collected in weekly increments for a total of 83 weeks (not necessarily consecutive, due to inadvertent data loss), from 1989 to 1991. Because implementation times varied for each of the different division of the department, each subdivision was analyzed separately. The number of examinations performed and measured during the study were 111,401.

Our reference standard was a direct on-line generation and verification technique. Inpatient plain radiographs were reviewed by a radiologist, and immediately entered into an on-line computer system (Sierep, Siemens Corporation, 1979), which automatically verified the report, and dispatched the report to a printer for generation. Reports were thus immediately available for the consultant as a function of the on-line system.

Digital dictation was analyzed within the Neuroradiology subdivision. This subdivision utilized traditional tape to typist methods, followed by manual editing and a return to the typist for finalization. They converted to a digital dictation system whereby reports were dictated into a telephone accessed computer and retrieved by a remote transcriptionist. Manual editing with return to typist for finalization was maintained. Time to verification/finalization was analyzed as either less than 24 hours, or greater than 48 hours, as a percentage of all reports generated.

Computer-based verification was analyzed in two subdivisions, orthopedics and nuclear medicine. These subdivisions utilized tape to typist techniques, with manual editing, and return to typist for correction and finalization. These subdivisions retained taped to typist dictation, but converted to on-line editing and verification of reports. Time to verification was analyzed as a percentage of reports verified in less than 24 hours, or greater than 48 hours, in both manual correction and on-line editing and verification methods.

RESULTS

For our reference standard of direct on-line generation and verification, 90% of all reports were verified within 24 hours. In only 4% of cases, verification was completed in greater than 48 hours. No significant change in either report generation or verification time was noted over the cumulative data collection period, except for transient seasonal aberrancies. (Fig. 1 & 2)

Digital dictation implementation resulted in an increase from an average of 32% to 78% of reports verified in less than 24 hours, and a decrease from 37% to 14% of reports verified in greater than 48 hours. (Fig. 3 & 4)

Direct on-line editing and verification of reports which had been transcribed from tape to typist techniques increased from 42% to 78% of reports finalized within 24 hours in the nuclear medicine subdivision, and from 59% to 86% in the orthopedics subdivision. Greater than 48 hour verification dropped from 39% to 9% in nuclear medicine, and from 30% to 6% in orthopedics. (Fig 5,6,7, & 8)

DISCUSSION

Automated dictation

Automated dictation systems such as the Sierep have several advantages over traditional reporting systems: the interval step of a transcriptionist is eliminated

(saving on variable personnel costs, as well as transportation time of tapes and reports), but the radiologist is able to see the finished product, with instantaneous editing capabilities. Referring physicians may immediately access the report at any remote site with on-line access, with confidence that they are viewing the finalized report. However, as the 90% less than 24 hour verification time experienced by our institution indicates, no system is perfect: some films are removed from the department before a radiologist may interpret them, which prevents the theoretical 100% of instant review from occurring.

On-line verification

On-line verification of reports permits the radiologist to dictate the examination in his or her preferred format. Even when traditional tapes are used, which entails transmittal of tapes, requisitions, etc. to a transcriptionist, the time to verification is still decreased dramatically as seen above. Computer-based verification was readily accepted by our radiologists after a brief accommodation and training period (approximately one month, as seen in Fig. x), largely due to ease of use of the simple editing formats available for most of the word processing programs. Electronic signature is presently accepted by legal departments, as simple security passwords limit general access to the verification process.

Digital Dictation

Digital dictation methods have two important advantages over traditional tape transcription coupled with on-line verification methods.. These include the ability of a transcriptionist to begin immediate typing of a report after dictation, without waiting for delivery of a tape. The transcriptionist may be at any location with telephone access to the computer, and even at home. Furthermore, this system permits immediate verbal retrieval capabilities of a preliminary report by the referring physician. A third option available on some digital methods includes automated telephone calling to referring physicians, which announces the availability of important examination findings.

CONCLUSION

There are multiple methods of reducing report turnaround. Three alternative methods were explored in this study, with positive results in each methodology. The results indicate that no one method alone will necessarily help to achieve desired standards for report turnaround. Having a system that allows tracking the phases of report generation from initial reading through final verification and printing is a necessary tool with which to manage the improvement of report generation. Depending upon the radiologists, the physical location of transcriptionists, and the workload, one may benefit using digital dictation or computerized reporting stations. The more alternatives available, the higher the probability of finding solutions that will be readily adopted by the physicians, transcriptionists, and technologists.

GENERAL DIAGNOSTIC

LESS THAN 24 HOURS

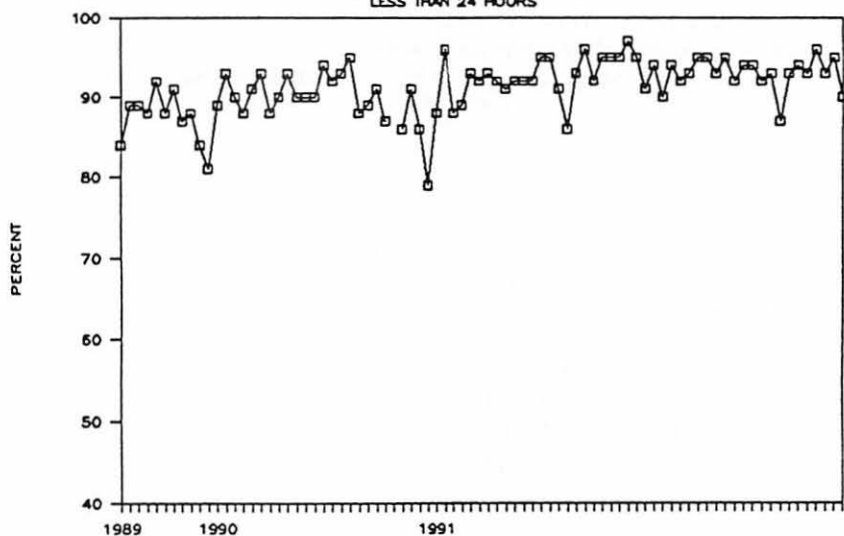


FIGURE 1 ON-LINE GENERATION & VERIF.

GENERAL DIAGNOSTIC

GREATER THAN 48 HOURS

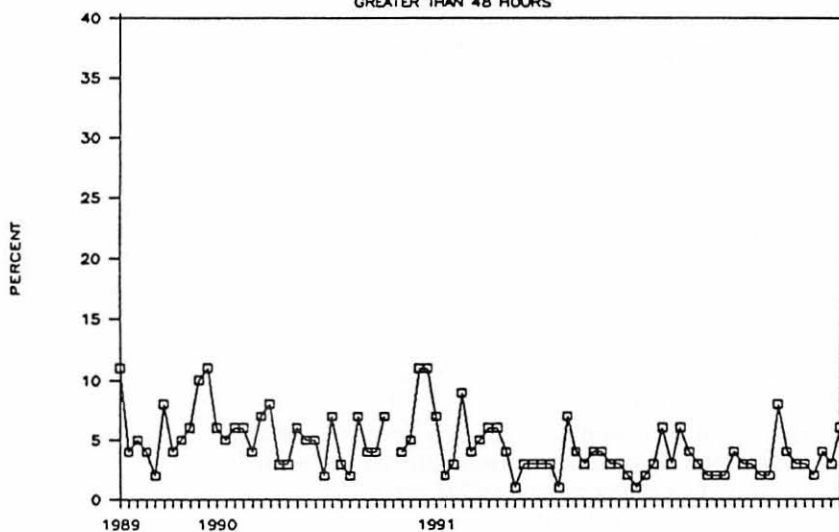


FIGURE 2 ON-LINE GENERATION & VERIF.

NEURORADIOLOGY

LESS THAN 24 HOURS

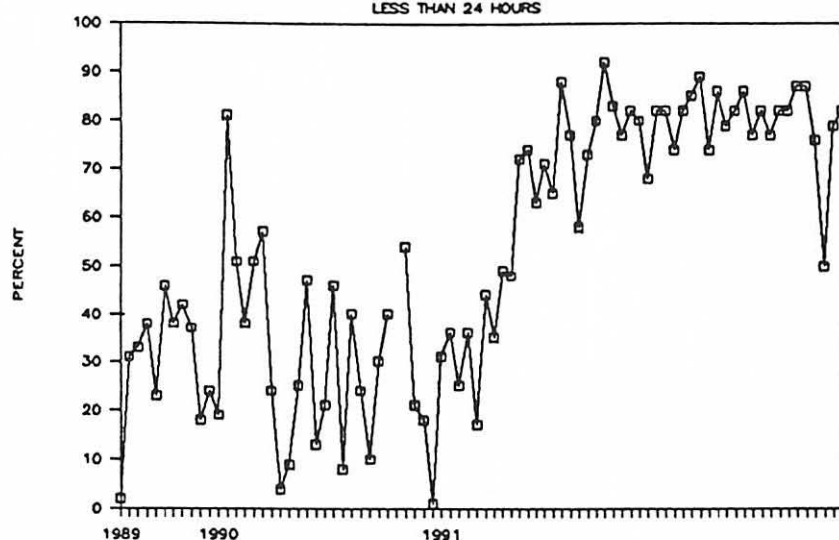


FIGURE 3 DIGITAL DICTATION

NEURORADIOLOGY

GREATER THAN 48 HOURS

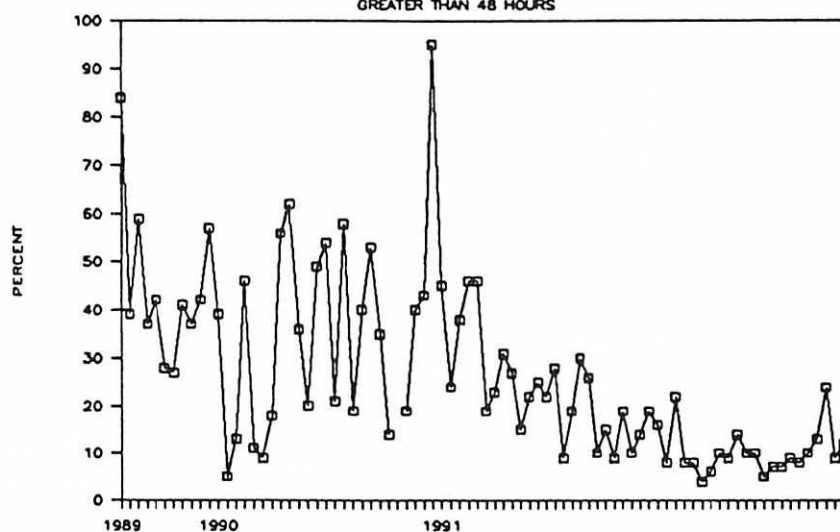


FIGURE 4 DIGITAL DICTATION

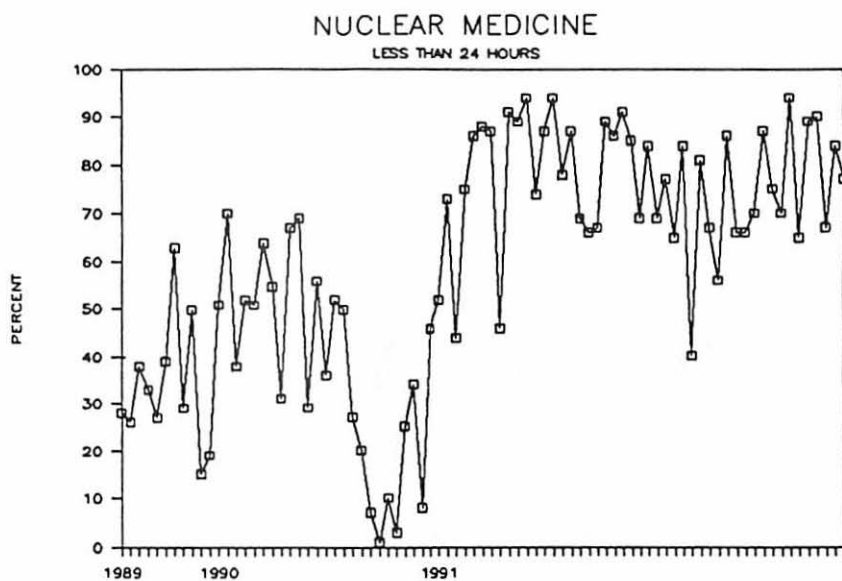


FIGURE 5 ON-LINE VERIFICATION

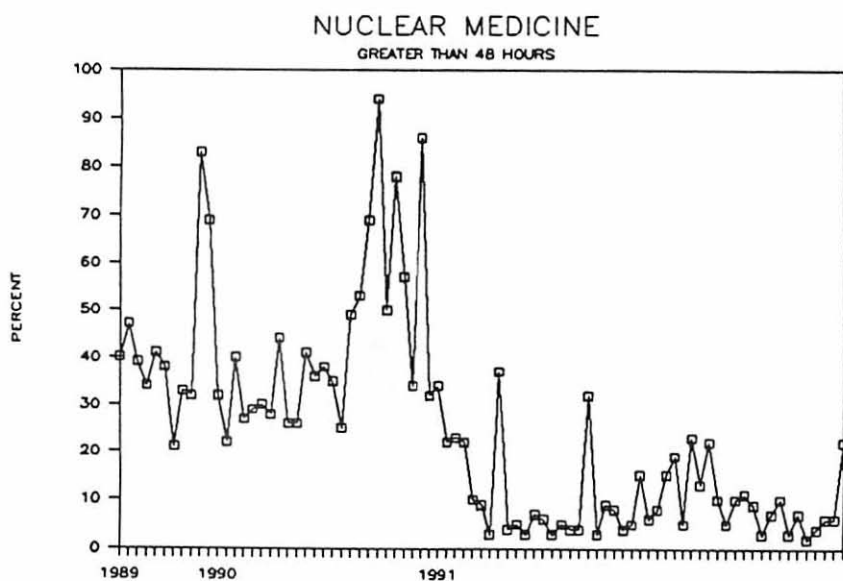


FIGURE 6 ON-LINE VERIFICATION

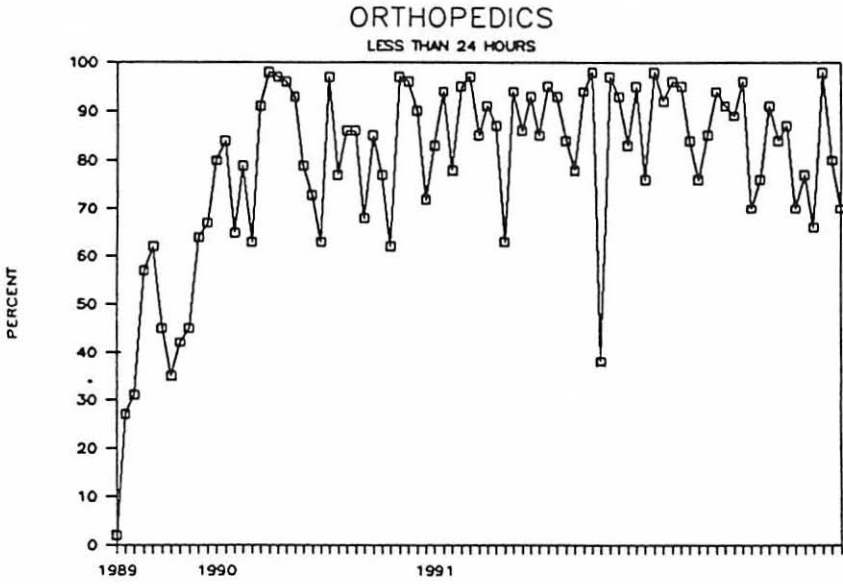


FIGURE 7 ON-LINE VERIFICATION

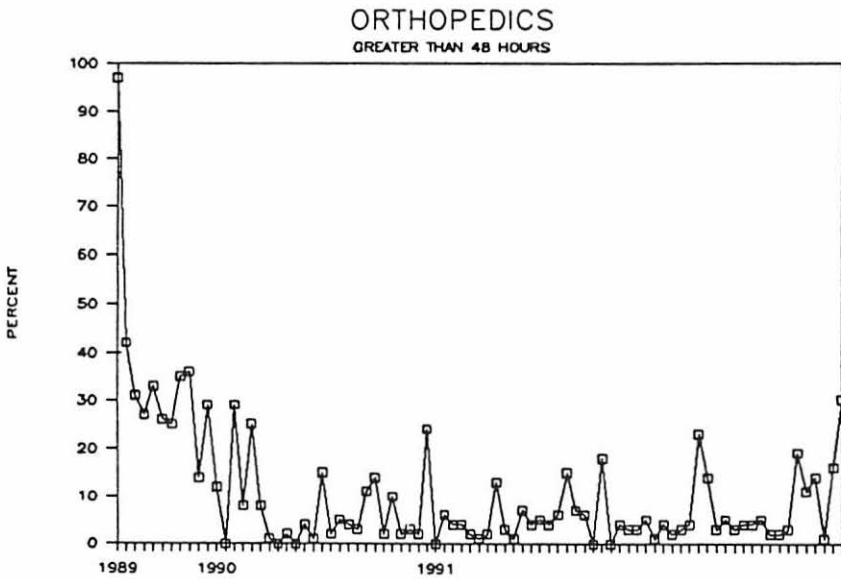


FIGURE 8 ON-LINE VERIFICATION

Case Study: Successful Use of Automated Speech Recognition in a Hospital-Based Radiology Department

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Automated speech recognition (ASR) has long been considered the linchpin of a radiology viewing and reporting workstation that will be eventually a front-end for PACS-based systems. While continuous speech technology is still several years away, structured reporting has proven itself to be effective for physician reporting for nearly all diagnostic imaging modalities.

The real-world experience to date of one hospital-based radiology department with ASR -- the VoiceRAD system from Kurzweil AI -- will be presented, where ASR enables clinical radiologists to dictate 90 % of their reports. The costs, benefits, advantages and shortcomings of using ASR will be discussed.

Background

Community-General Hospital (CGH), Syracuse, New York, is a 356-bed (including 50 beds in an on-campus Skilled Nursing Facility), full-service community hospital providing outpatient and in-patient tertiary care for the greater Syracuse area. The radiology department, and indeed the hospital as a whole, has experienced moderate increases in visits from year to year. The Syracuse area has three private not-for-profit hospitals, a State medical center hospital and a Veterans Administration (VA) hospital.

The diagnostic imaging department is a busy one and has experienced the resource and budgetary strains of an increase in patient visits without a corresponding increase in resources. In calendar year 1991, the department performed and interpreted approximately 89,000 scans. The department provides a broad range of radiologic imaging modalities, including computed tomography (CT), mammography, general radiology, nuclear medicine, ultrasound examinations, and special procedures. The radiology department is comprised of a staff of 7 radiologists, one full-time administrator, 34.5 (FTEs) technicians and 22.5 (FTEs) additional administrative support.

History

From the hospital's inception in 1963 until 1989, the method used for radiologic reporting has been radiologist dictation, the transcription being performed by hospital stenographers. Despite the presence of an experienced staff of radiologists, service to both the hospital and outpatient referring physicians had suffered due to frequent, recurring episodes of tardiness of transcription of reports.

While the department was providing high levels of diagnostic impressions, by 1988 the slow turnaround by transcription caused the manager of radiology and the chairman to take drastic action to correct the problem. The department analysis of the issue determined that the "major cause of the lack of ability to provide timely transcription is human. Problems have occurred due to termination, sickness...and inexperienced transcriptionists causing extensive periods of low productivity and quality. The possibility or occurrence of errors in reviewing and signing reports by radiologists...is inherent in the present system." Transcription on weekends and holidays was inadequate or non-existent. The department, as well as the hospital's quality assurance and risk management committees, concluded that even the best radiologic interpretations were nonetheless diminished by delays in transcription, which was threatening the provision of good patient care.

In order to meet legal and quality assurance objectives of hard copy reports to the medical record, handwritten, abbreviated temporary reports were generated by the radiologist on all in-patients. These became a permanent part of the record even after transcribed report was available. This is still policy for the cases transcribed at this time (those not dictated using VoiceRAD), so as to meet the requirements for rapid charting of imaging procedures.

The department began to research alternative methods of providing a permanent solution to slow report turnaround that would also guarantee a high degree of reliability and accuracy in diagnostic radiology reports. Tradeoffs between adding additional transcription staff versus new reporting technology were weighed, and research into alternatives to traditional transcription tanks and digital dictation were investigated.

Voice Recognition: An Emerging Technology

CGH researched the capabilities of automatic speech recognition (ASR). Automated speech recognition is a technology that

"hears" individual words spoken and enters corresponding text directly into the file on the computer. Past research¹ with moderate, 1,000-word discrete speech systems had shown that voice recognition was appropriate for many types of reports that were created by reviewing a range of radiologic scans.

At the 1987 Radiological Society of North America (RSNA) meeting, Dr. Alan H. Robbins, professor of radiology at the Tufts University School of Medicine, reported on the successful development of the first voice-activated radiology reporting system from Kurzweil Applied Intelligence. One year later, Dr. Robbins returned to the RSNA to report on a much-expanded version of the system.

VoiceRAD is composed of three modules:

1. voice recognition hardware and software. The A/PA (Acoustic/Phonetic Analyzer) AT/XT form factor board accepts analog input from either a telephone-like handset or headset and digitizes each word. Software in memory apply linguistic, phonetic, acoustic and other models to make a "top choice" recognition candidate, as well as the four most similar-sounding words, which appear for the radiologist to choose from in the unlikely event of a misrecognition. The user may add new words to the vocabulary, or train existing ones with new samples, or make slight alterations to recognition parameters using menus to "tune" recognition.

Current VoiceRAD systems are speaker-independent. Each word comes pre-trained with generic voice samples provided "from the [software] factory." As each radiologist uses the system, it adapts, as the system automatically begins to re-weight the speaker-independent samples with each utterance of the radiologists' own speech.

¹ Alan H. Robbins, MD, et al., "Speech-Controlled Generation of Radiology Reports," *Radiology*, Volume 164, Number 2, August 1987), pp. 569-73.

Speaker-independence was a breakthrough which Kurzweil first provided the market in January, 1990 with Version 3.0. CGH purchased the system with version 2.0, which required those radiologists having to spend significant amounts training the system. Radiologists beginning in 1990 and beyond have not needed to train the system and have in general received high levels of recognition with the system.

2. Structured reporting software, which manages the user interface, and provides document processing-like features (line wrap, printing, saving documents, etc.);
3. The knowledge base, which is comprised of the words which generate actual text on the screen. The user can use any or all of the following knowledge base features to help generate reports directly into the computer:
 - "trigger phrases," utterances that instruct the program to retrieve from its computer memory complete, often lengthy passages of report text;
 - "fill-ins" prompts with brackets where the system asks for specific information about the film presenting to the radiologist. For example, if a physician utters mass to VoiceRAD, the system puts corresponding text on the screen indicating that there is a mass which has been observed. Prompts within the new text on the screen prompt the physician for [left or right breast], [location or quadrant or o'clock'], [size], and whether the [margins are [ill-defined or well-defined]]. Each bracket has a corresponding word list for all appropriate information;
 - Free-text capability, a large vocabulary of common radiology terms. The system CGH evaluated in 1988 was a 5,000-word recognizer, meaning that the system accommodated up to 5,000 free-text words.

Example of VoiceRAD Screen Interface

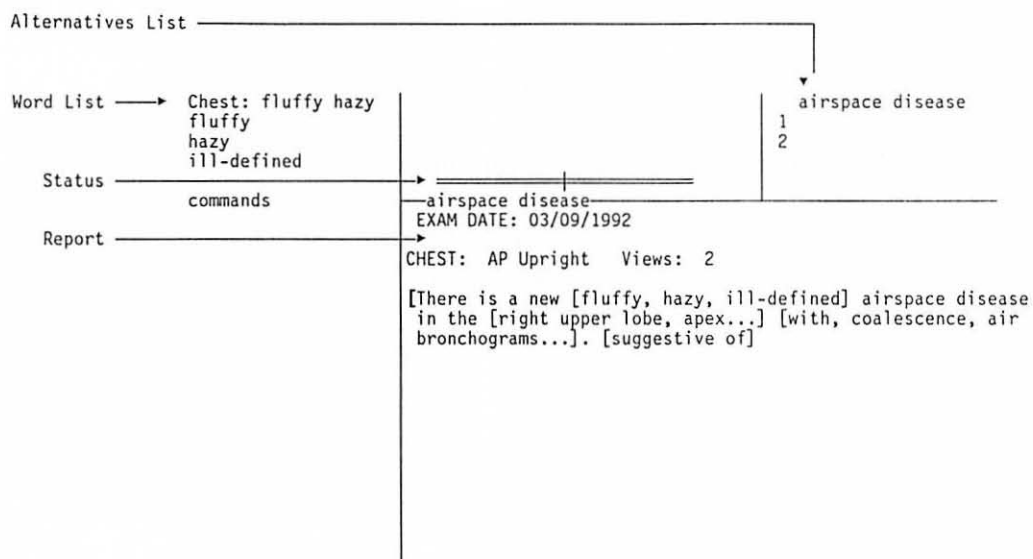


Figure 1 The major Dictation screen areas

The above graph appears a brief schematic of the VoiceRAD interface. The bottom screen depicts a sample report dictated with VoiceRAD.

		signature	1 temperature
			2 significant
			3 admission
			4 taken
EXAM DATE: 04/09/92		signature	
CHEST: AP UPRIGHT VIEWS: 1			
Prior exam: None.			
There is a new hazy airspace disease in the right upper lobe with coalescence. This finding is suggestive of pneumonia. There is new mild compressive atelectasis in the right upper lobe. There is a stable 1.1 cm x 1.5 cm spiculated nodule in the left lower lobe. This nodule overlies the ribs.			
IMPRESSION:			
1. Possible nodule, left lower lobe			
2. Pneumonia, right upper lobe			
Elizabeth Blackwell, M.D.			
Thu, Apr 09, 1992 01:00 PM			

Screen showing a chest report

Additionally, ongoing research by medical users of ASR was being done to test whether voice-created patient reports could be quantitatively proven to provide superior medical care in radiology or other medical specialties². That research bore fruit as CGH was in the process of installing the system.

Gaining Staff Commitment Beforehand

Prior to the installation of VoiceRAD at the department, the chair solicited commitment in writing from all department radiologists that:

- the chairman would be the initial, or lead, user to assist with customizing the knowledge base for the department's needs;
- once the necessary software alterations had been made, the other radiologists would commit to using VoiceRAD as the solution of choice for insuring instant, typed reports.

Summary of Results

The department has met or surpassed all goals for system performance set down prior to installation. Prior to VoiceRAD's introduction:

- the cycle for manually transcribed radiology reports was reported to be from two to four days;
- the reported error rate for transcribed reports was reported to be in the range of five percent; and
- transcription services were limited to eight hours over a five-day week and four hours on weekends.

² John Holbrook, MD, and Richard Aghababian, MD, "A Computerized Audit of 15,000 Emergency Department Records, *Annals of Emergency Medicine* 19:2 (February 1990): 139.

The goals prior to installation that the department set down were:

- have complete reports available on the hospital's clinical information system (CIS) as soon as possible;
- produce at least 70 % of the reports with VoiceRAD; and
- increase productivity of the department.

After VoiceRAD was installed:

- reports are instantly transmitted to the CIS for review as available on nursing units and clinicians' offices, if in the physicians' office building only, for security reasons;
- department usage is at 90 % of all cases;
- physicians' interruptions are down 95 %, increasing productivity and enhancing the department's professional image.

Summary: Productivity and Financial Gains

A professional productivity study³ of the positive impact of VoiceRAD on the department was performed in late 1990. The summary of the findings concluded that:

- Time on task, defined as the average time for reading, recording, and providing an instant, printed report to the information system, averaged 45 seconds for an analysis of over 50 reports. Compared to the two- to four-day wait for a completed report from transcription, VoiceRAD provides an approximately 7000 % improvement in throughput.

- Physician interruptions due to clinicians and medical records asking for the location of radiology studies were reduced by 95 %, since the reports were instantly completed and sent to the clinical information system.
- A study of system utilization concluded that "VoiceRAD use promotes further use with consistent gains in efficiency." The two senior radiologists, Dr. David Cheris and Dr. William Goldman, regularly use the system for 100 % of their work, which often involves large daily volumes of interpretation. On one particular day of study (October 8, 1990), for example, Dr. Cheris produced 177 reports with VoiceRAD.
- Quality gains, though difficult to measure, are believed to be positive. One tangible measure, the cost of quality, defined as the cost of detecting and correcting errors in reports using manual transcription, was brought to almost zero with VoiceRAD, since reports are accurate at dictation time and do not have to be reread.
- Financial benefits were easily measurable and positive. The summary of financial gains by the study, in conjunction with assistance from department and hospital management, concluded that:
 - return on investment (ROI) over five years is calculated at 72 %;
 - the hospital's internal rate of return is 24 %;
 - payback has already occurred at 2.9 years.

Summary

The VoiceRAD system has had a positive impact on the radiology department at Community-General Hospital. Feedback from clinicians and medical records indicate that it has rapidly speeded up the flow of patient records to the appropriate departments and individuals.

Recently, the department upgraded its 5 standalone systems to a local area network (LAN), which is expected to make physicians more efficient. With the LAN in use, radiologists do not have to "sneakernet" their latest voice profile software from one machine to another. The voice files are automatically downloaded from the server to the appropriate dictation workstation, and stored when the radiologist has completed work.

The Human Transcriptionist: The Standard for Speech Recognition Systems

Byrn Williamson Jr. and Barbara J. Plenge

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I. Introduction

In the past decade, automated speech recognition systems have moved from the experimental laboratory into clinical use in radiology, and further improvements are being made continually. Speech recognition systems offer potential benefits compared to conventional transcription which involves recorded dictation of the radiologist's interpretation, subsequent transcription by a typist, and still later review and authentication by the radiologist. On the other hand, current speech recognition technology has a number of significant limitations.

For more than 40 years radiology reports at the Mayo Clinic have been transcribed on-line by direct dictation from a radiologist to a typist. Although in recent years we have begun to use recorded dictation for some examinations, 70% of radiology reports are still generated by direct dictation. Comparison of direct dictation with currently available automated speech recognition technology provides insights into the characteristics of an ideal speech recognition system. In some cases direct dictation is preferable to either conventional recorded dictation or current automated speech recognition systems.

II. Direct Dictation Process

At Mayo, direct dictation typically occurs during a continuous reporting session. The radiologist is seated at a viewbox with a stack of radiographic examinations. An x-ray report form, which already contains demographic information and appropriate information about the examination (Fig 1), has been placed on top of each examination. The radiologist begins the interpretation process by placing the x-ray report form in the transcriptionist's typewriter and placing the films on the

viewbox. The transcriptionist positions the report form in the typewriter and transcribes the radiologist's report as it is dictated (Fig 2). Reports are typically brief, including only positive findings and significant negative findings. A "telegraphic" style is employed. We have found that brevity speeds the process of transcription and is appreciated by referring physicians because it reduces the time required to read radiographic reports. When the radiologist has completed interpretation of the films, they are placed in a stack next to the transcriptionist, and the completed report form is placed on top of the examination. The process is repeated with the next examination. At frequent intervals a film clerk collects the reports and films and takes them to a nearby area where the examination is jacketed and the report is pasted on the outside of the film jacket. Copies of the reports are also sent at frequent intervals to referring physicians. Films and reports are routinely in the hands of referring physicians within two to four hours of performance of the examination.

X-RAY EXAMINATION	
Mayo Clinic	
3 743 627 ALRGYC W-15C	STAFF M.D. T Jones
SMITH, GEORGE	PAGER NO. 4-7810
M 72	ROOM
TECH BW-2	Pts. Age 72
	Legal Case ☐
	1
Indication for Exam. Pain	
Exam Requested @ Elbow	
DATE TO BE PERFORMED _____ PRESS FIRMLY WITH BALL POINT PEN	
PATIENT NEEDS ☐ WC ☐ CART TRANSPORT TO X-RAY	
MC47/R991	

Figure 1. X-Ray Request/Report Form



Figure 2. Typical Direct Dictation System

III. Requirements for Successful Direct Dictation

Direct dictation can be a rapid and efficient method for producing radiographic reports, but certain requirements must be met. In particular, the process requires transcriptionists with excellent typing skills. The pace of reporting can be quite rapid, and the transcriptionist must be able to type rapidly and accurately and must have the ability to perform in a stressful environment. At times the transcriptionist must distinguish the text of the report from editorial comments addressed to residents or other physicians.

The speed of dictation and the speed of transcription should be approximately equal. In general, this requires that analysis of radiographic findings be accomplished quickly by the radiologist and that the report be brief. Thus, we have not found direct dictation to be an efficient method for interpretation of complicated examinations requiring detailed analysis of numerous images such as angiograms, CT scans, ultrasound examinations, and MRI.

The time required for the transcriptionist to sign off one examination and prepare for the next report should be brief. Within a matter of seconds the radiologist can place the films of one examination in the interpreted stack, place the films of the next examination on the viewbox, and begin dictating. The speed of this process places stringent requirements on the time available for the transcriptionist to complete one report, place the report on the interpreted films, and position the next report form in the typewriter.

IV. Comparison of Direct Dictation with Automated Speech Recognition Systems

Both direct dictation and automated speech recognition systems provide for timely transcription of radiographic reports. As soon as the radiologist interprets the examination, the text is transcribed. This process eliminates the time lag between dictation and transcription inherent in the use of most recorded media. In addition, both direct dictation and automated speech recognition systems provide for instant authentication of examination results thus eliminating the time-consuming process of subsequent review and signing reports by the radiologist.

Direct dictation has several significant advantages compared to current speech recognition systems. The human transcriptionist recognizes continuous speech, and there are no constraints on terminology or report structure. The human transcriptionist recognizes an extremely high percentage of the words spoken by the radiologist, and when a word is not understood, the transcriptionist can immediately ask for clarification. Thus, the radiologist does not have to be distracted by the continual need to confirm that words and phrases have been transcribed accurately. Once the report form has been inserted into the typewriter, the radiologist's entire attention can be devoted to handling and interpreting the films. In summary, the direct dictation process is non-intrusive. This has two practical implications. First, the radiologist's attention is not diverted from the films, so important findings are less likely to be overlooked or omitted. Second, the radiologist's time is used efficiently, and productivity is maximized.

The human transcriptionist can perform important quality assurance functions such as confirming that the report form matches the examination being interpreted. Experienced transcriptionists can also provide a degree of error checking, questioning terms or findings that seem inappropriate.

Automated speech recognition systems have several advantages compared to direct dictation to a human transcriptionist. Speech recognition systems can be available twenty-four hours a day to facilitate timely transcription of examinations performed outside of normal duty hours. In addition, speech recognition systems are well suited to intermittent dictation because they do not incur expenses for salaries and benefits when they are idle. Speech recognition systems can be programmed to produce canned reports consisting of phrases, sentences, or complete reports in response to a single trigger word or phrase. Because our reports are typically brief, this capability is of limited interest in our setting, but it may be helpful in some circumstances. Speech recognition systems can be quite cost-effective compared to the cost of salaries and benefits for a human transcriptionist.

V. Conclusion

Direct dictation and automated speech recognition systems both offer advantages for the production of radiographic reports. The ideal transcription system would provide:

- 24 hour availability
- Low cost
- Rapid availability of reports
- On-line validation of reports
- Continuous speech
- High recognition rate
- Speaker independence
- No constraints on terminology or report structure
- Hands-off operation
- Non-distracting
- Error checking
- Availability of canned reports

The Radiology Conference – a Demanding PACS Application

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Introduction

The practice of radiology is organized differently in different parts of the world. In Scandinavia the radiology conference is an important part of the organization. Each morning several clinicians, ranging from senior experts to medical students, gather in a special room in the radiology department to go through the current cases in one of the radiological subspecialties e.g. neuro-radiology. Typically 20-30 persons attend the 30-45 minute session during which the responsible radiologist presents 30-40 cases. The sessions serves both a clinical and an educational purpose, exposing everyone to a wide range of patient cases on a daily bases. The current film based radiology conference is based on selected films from each case being mounted in advance in an alternator light box. The different cases can then be exchanged in a few seconds, at least when they are presented in sequence.

As more and more parts of the radiology service is becoming based on digital technology and PACS it is a great challenge to develop a system that can handle the requirements of the radiology conference. In a joint project between The Radiology Department at Lund University Hospital and IMTEC Imaging Network AB and with economic support from The National Swedish Board for Technical Development we are developing and testing such a system. It is based on a workstation with a special software that allows a radiologist or assistant to prepare in advance a series of screen layouts with selected images from each case. During the conference these layouts can be brought up on the large display screen in single seconds.

Technical description

The digital radiology conference system is one part in a PACS that step by step is being installed at Lund University Hospital. The images that are produced at different sources in the PACS can be stored in the image archive and then be picked up at connected display stations, e.g. the workstation used in the radiology conference room (Fig.1). The IMNET high speed fiber-optical network, designed for fast image transfer, and marketed by IMTEC, is used in the PACS system to connect the different nodes (1).

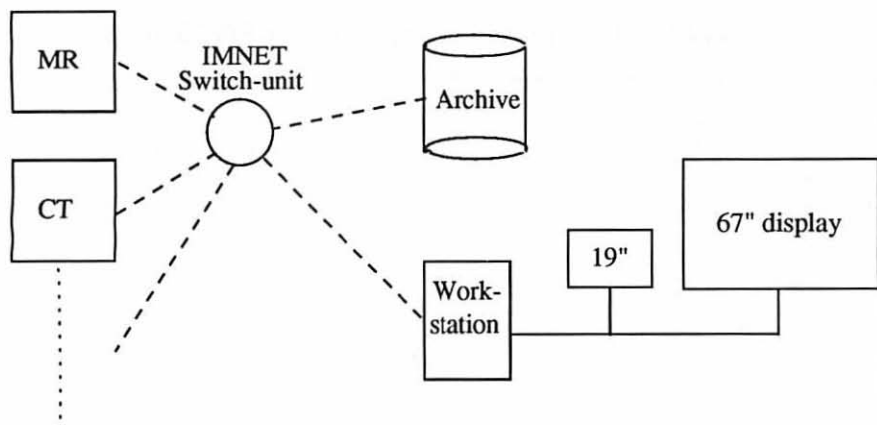


Figure 1. The relevant parts of the PACS at Lund University Hospital

The workstation used in the radiology conference room is based on an Image 1200 radiology workstation from IMTEC. It has for this project been equipped with two displays with resolution 1280*1024 which are connected in parallel i.e. showing the same images.. One is a normal 19" monitor that is used in the preparation phase and one is a 67" monitor or high resolution video projector used at the radiology conference when the pre-defined screens are to be displayed for the audience. The workstation allows the use of multiple monitors showing different images but this has not been used in this project since it has been considered more valuable to have the possibility of enlarging individual images to cover the whole large display screen. The RAM-memory in the workstation is big enough to keep images for three screen layouts in memory simultaneously, this is necessary in order to have a quick response when the radiologist bring up a new screen at the radiology conference.

Preparation phase

Before the preparation phase start, all images that are to be used must first be sent from the image sources to the archive in the PACS. Then it is possible to fetch the images from the workstations in the PACS e.g. the workstation at the radiology conference.

The radiologist or assistant start the preparation phase by selecting a pre-defined layout of the screen from a list of available ones ranging from (1*1) to (6*4). Each position in the selected layout is then filled with an image slice selected from all the available slices. The brightness and contrast values are automatically stored together with the image slice. The different positions can be filled with image slices from different studies for comparison.

A specially developed software module is used during the preparation phase to simplify the selection of image slices and display parameters for each position in the layout. All the normal image handling and processing functions of the workstation are available during the preparation. It is also possible to store a comment together with each image slice, this comment is then displayed together with the image slice at the presentation. At any time during the preparation the resulting screen can be visualized exactly as it will be at the conference.

When a screen has been completely defined, it is stored in a list and the radiologist could go on with the next one. Storing a screen means that the identifications of the images together with display parameters are stored, not the images themselves.

The screen layouts can be stored in different lists so it is possible to handle sets of screens for different radiology conferences separately.

Presentation phase

The user interface for the presentation phase has to be extremely simple to handle since it has to be used while talking to an audience. This has been achieved through the use of the pre-defined screen layouts that have been prepared during the preparation phase.

In normal operation the responsible radiologist simply selects the list for today's session and then goes through this list by pushing the button for "next screen". Each time he pushes this button the display is instantly updated to the next pre-defined case. All images are normally stored in the archive and are transferred to the workstation over the IMNET optical network. When images referenced by the selected screen has been loaded into RAM-memory and displayed according to the stored display variables, there is a background process started to handle transfer of images referenced by the next and previous screens into RAM memory. This pre-fetch results in a very quick response when the radiologist selects the next or previous screens in the list.

But the radiologist is not limited to this simple sequential operation. Whenever he wants to show another one of the pre-defined screens it is selected from the list that was generated during the preparation phase. Since this disrupts the pre-fetching it may result in a few seconds loading time. This corresponds to flipping through to another part of the alternator magazine in the conventional film based conference.

During the presentation phase all individual slices in the layout are freely accessible for zooming, windowing or other viewing functions. Behind the pre-defined slice in each position of the screen layout the whole image stack is loaded so a displayed slice can easily be changed to a multi-format display, to another slice in the image or to a movie moving up and down the stack. This function is very fast since all slices are loaded into RAM-memory, not only the displayed slice.

One important feature is the quick zoom that enlarge an image to full screen size

with just one button press. This function make it possible to enlarge an image so that all persons at the radiology conference can look into details in the image slice. This function corresponds to the video enlargement equipment that is used in the film-based radiology conference.

The normal functionality of the workstation e.g. functions to measure in images, to filter images and to display images in a simple 3D-mode is also available during the presentations but less frequently used due to time constraints during the busy conference. All the functions of the workstation are accessed through pointing and clicking in a limited number of menus. No keyboard is needed at all. After some training it is possible to operate also the more advanced functions while discussing cases in front of an audience. And in the simplest mode of operation only the "next" and "previous" buttons need to be pressed.

Clinical user experiences

The PACS at Lund University Hospital is still in an early stage of extension. So far the only image sources relevant to the Neuroradiology conferences where the system is being tested are an MR system and a tele-radiology link to a CT in another cooperating hospital.

Therefore, only MR examinations performed in patients from the Department of Neurosurgery and a single CT examination from the other hospital have been shown using the system during the daily neurosurgery conference. The system has been used by different neuroradiologists during these neurosurgery conferences. Cut-films have also been available during the test period. The basic functions of the system have been easy to learn and an estimated training time of a couple of hours would be sufficient for learning the most important functions.

The **major advantages** of the system compared to showing the conventional cut-films have been the following:

The image quality has been significantly improved since we are working with digital raw data. The window-width and level have been easy to adjust to optimize the presentation of the different lesions. Images from new and previous examinations, as well as before and after contrast, have been possible to place beside each other on the monitor for easiest comparison. It has also been easy to pick up selected images from the different series of the examination.

The **major draw-backs and problems** have been the following:

The radiologists have felt that the time needed to prepare the presentations has added to their already high workload. To minimize the workload for the radiologist it is important to organize the system so that all new and old examinations routinely are loaded into the system by the MR or CT technician on duty. Since CT and other modalities in the hospital have not yet been connected, comparison with these modalities has not been possible in the system at present.

Another problem has been caused by the fact that the present version of the system is controlled by a mouse connected to a cord. A more advantageous situation would be to use a remote control cordless mouse, so that the radiologist can interact better with the audience and is free to move around in the conference room. The radiologist in charge of the conference has so far been forced to work with the mouse in front of the 19" display unit, whereas the audience has seen the images presented on the 67" display unit. This leads to a lack of contact between the radiologist and the audience since they are watching different monitors. Preferably the radiologist should be able to use the mouse directly with the large screen.

During the initial part of this project different kinds of large display units, both back projection and front projection types have been tested. The quality of the images presented on the large display unit has been variable with the different tested units and is an important factor for the system to be used at its full advantage.

Discussion

The initial experiences with the developed system has shown that it is possible to use a PACS based workstation also for such a demanding application as the Scandinavian radiological conference. The predefined screen layouts, including selection of slice and window settings has made the displayed images immediately available for visual evaluation without further need for interactive manipulation in most cases. Still the possibilities of flipping through the stacks and instantly zoom an image to full screen has made more detailed analysis readily available. The pre-fetching of the next (and, when relevant, previous) case has minimized waiting times. During the average discussion time of 30-90 seconds per case several megabyte of image data can be pre-fetched and loaded into RAM. Waiting times of this length between cases would be completely unacceptable.

Cordless alternatives to the interaction device (mouse) will be tested as well as new types of large screen display units in order to optimize the hardware components used in the conference room.

So far only a limited magnetic disk based archive has been used for image storage. When this is extended to a full size archive with a layered storage approach including optical disk drives and a juke-box and when more imaging devices are connected a higher load will be put on the network. This will be compensated for by the upgrade from the present IMNET 1 with its 10 Mbit/s transfer rate to IMNET 2 with its 140 Mbit/s rate (2).

Only continued development and testing work can show if digital image handling can completely replace the film based radiology without a loss in efficiency or quality, also for the demanding radiology conferences. But at least so far our experiences are positive, indicating that this is indeed possible.

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SESSION 11

Image Processing

Chair: R. Gilbert Jost

Digital Portal Radiography in Radiation Therapy

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Introduction

The actual practice of radiotherapy involves new and more accurate methods for target volume delineation and three dimensional dose distribution calculations. Additionally, highly accurate simulators and irradiation equipment are used. In order to optimize dose distribution to the target volume and minimize side effects to normal tissues the actual dose delivery to the individual patient has become even more important. To assure proper patient and beam alignment during radiotherapy the only method still commonly available is the radiotherapy portal film (1). However, conventional verification films suffer from low contrast resolution, due to the dominance of Compton interactions at therapeutic energies, which results in minimal attenuation differences between bone and soft tissue (2). Thus the precise geometric localization of both anatomic and non-anatomic structures is often quite difficult.

In the past various attempts have been made to improve the quality of megavoltage portal imaging, ranging from enhancement of the developed radiograph by an additional photographic step (3) or by digital image processing (4, 5) up to systems using alternative detectors of various kinds (6 - 8). Preliminary results of megavoltage portal imaging with storage phosphor plates as detectors were encouraging (9 - 11), though the performance and cost-effectiveness of the system has not yet been fully established.

The purpose of this work was to evaluate the performance of digital luminescence radiography (DLR) for megavoltage portal imaging in different treatment settings (esp. mantle-field irradiation) in comparison with the conventional film-screen system (Structurix D2 / steel-screen cassette) used in our department.

Methods

In the first series 33 pairs of digital and conventional verification films of various irradiation ports (e. g. head and neck, lung, mediastinum, abdomen, spine, pelvis) of patients ($n = 21$) and an anthropomorphic phantom ($n = 12$) were obtained. Portal images were taken with either Co-60 ($n = 4$) or 8 / 15 MV x-rays from Philips SL75, Siemens Mevatron 77 and Mevatron KD accelerators. The second series consisted of

22 pairs of mantle verification radiographs of patients and 6 of an anthropomorphic phantom from irradiation with 15 MV ($n = 19$) or Co-60 ($n = 9$) x-rays.

An Agfa cassette with steel intensifier screens (12) on the front (1mm thick for Co-60, 2 mm for 8 / 15 MV x-rays) and the back (0, 5 mm thick for Co-60, 1 mm for 8 / 15 MV x-rays) was loaded with a conventional film or a storage phosphor screen and fixed to a cassette holder.

For conventional radiographs we used the Agfa film Structurix D2 with a processing time of 8 minutes.

The radiation dose on the conventional film was 0,15 - 0,25 Gy, that on the luminescence screen 0,01 - 0,03 Gy.

For digital verification radiography the Siemens FCR-7000 Digiscan system was used. The photostimulable phosphor imaging plate was put under daylight conditions into the same cassette used for conventional verification films, exposed, and then put back into the computed radiography cassette, which was processed in the Digiscan reader unit by an auto- or semi-mode program that automatically controls density and contrast of each image (13, 14). Digital radiographs were printed as hardcopies in the single or double (two different windows) image output format. Post-processing was unnecessary in most cases.

Digital luminescence and conventional portal radiographs were evaluated by three radiotherapists and one radiotherapy physicist.

Evaluation criteria included contrast and spatial resolution, delineation of anatomical structures - like vertebral upper or lower plates, ribs or spinous processes, which were marked on each image -, delineation of block position, demarcation of the irradiation field and therapeutical value.

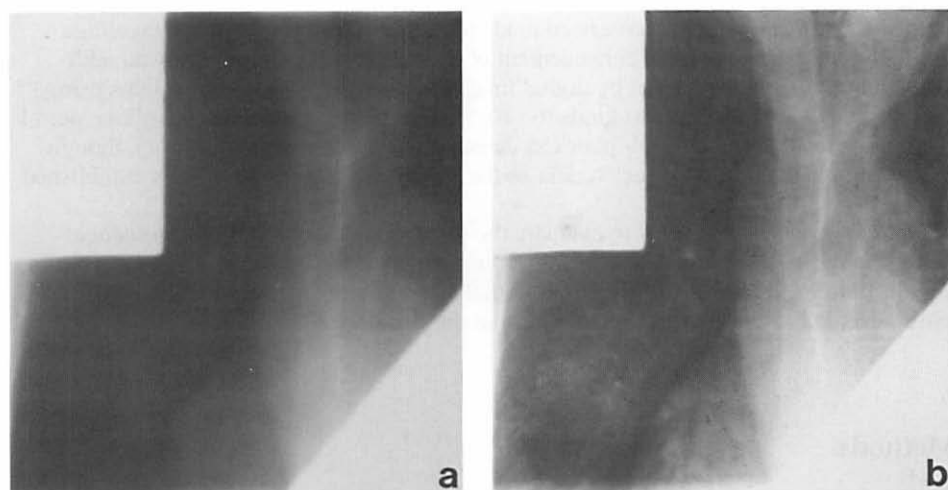


Fig. 1. AP field for irradiation (8 MV photons) of lung and mediastinum of a patient with lung cancer. Conventional film-screen technique (a) and computed radiography image (b). Note the increased contrast and visualization of the paracardial mass and the bony structures on the digital image (b).

Digital and conventional images were evaluated at individually optimized viewing conditions. Rating categories were specified as better, equal or worse.

Results

Results of the first series of portal images are shown in Table 1.

Table 1. Evaluation of 33 pairs of digital (D) and conventional (C) verification images (Co-60, 8 / 15 MV) of various irradiation ports

	D > C (%)	D = C (%)	D < C (%)
Contrast - air / soft tissue	47	51	2
Contrast - bone / soft tissue	37	61	2
Visualization - anatomical structures	29	52	19
Sharpness - anatomical structures	6	13	81
Demarcation - irradiation field	26	63	11
Therapeutical value	0	89	11

On digital portal radiographs both the contrast between soft tissue and air as well as soft tissue and bone was judged superior to conventional images (Fig. 1). Visualization of anatomical structures like the spinous processes was comparable with both methods. However, digital radiographs suffered from a lower spatial resolution, so anatomical details appeared more blurred. The optimal brightness level of digital images improved the demarcation of irradiation fields. Except for Co-60 images the therapeutical value, i. e. decisions influencing the treatment set-up, was comparable with both techniques.

However, the four digital images produced by irradiation from a Co-60 source showed an obvious field edge ambiguity because of the digital enhancement technique (Fig. 2). Therefore the therapeutical value of these images was judged inferior to conventional port films.

In the second study digital and conventional portal radiographs of mantle-radiotherapies were compared.

The results of 19 cases irradiated with 15 MV x-rays are shown in Table 2.

Again digital portal radiographs provided a superior contrast and a better visualization of anatomical structures than conventional ones. The optimal brightness level and the good contrast resolution of digital images helped to determine the position of lung

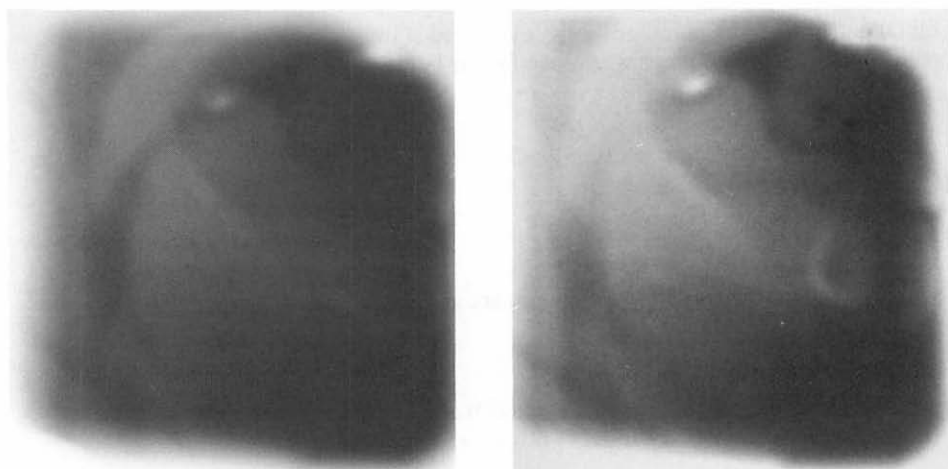


Fig. 2. Co-60 conventional (a) and digital (b) portal film of a lateral oropharynx field. Whereas the overall image quality is comparable with both techniques, the penumbra area on the computed radiography image on the right (b) is irregularly diminished because of the digital enhancement technique.

Table 2. Comparison of 19 digital (D) and conventional (C) portal radiographs of mantle radiotherapy (15 MV x-rays)

	D > C (%)	D = C (%)	D < C (%)
Contrast - air / soft tissue	84	16	0
Contrast - bone / soft tissue	84	16	0
Visualization - anatomical structures	66	26	8
Sharpness - anatomical structures	8	20	72
Position of shielding block - cranial	53	42	5
Position of shielding block - medial	65	35	0
Position of shielding block - lateral	7	65	28
Position of shielding block - caudal	47	49	4
Speed to define block position	60	40	0
Therapeutical value	40	60	0

blocks exactly and quickly, though the delineation of the lateral borders of lung blocks was found to be more difficult on digital radiographs as a result of artefacts caused by edge-enhancement algorithms.

Decisions influencing the treatment set-up of mantle-field irradiations were facilitated by digital portal images.

The digital mantle radiograph (Fig. 3) offers a good contrast resolution and an optimal brightness level and admits a quick assessment of patient and block positioning errors. Even the lower thoracic vertebrae are well demarcated. However, the edge-enhancement algorithm used to produce the digital image results in artifactual black and white bands at the interface of the lung blocks and the surrounding areas, which renders the delineation of the lateral border of the right lung block more difficult (3b).

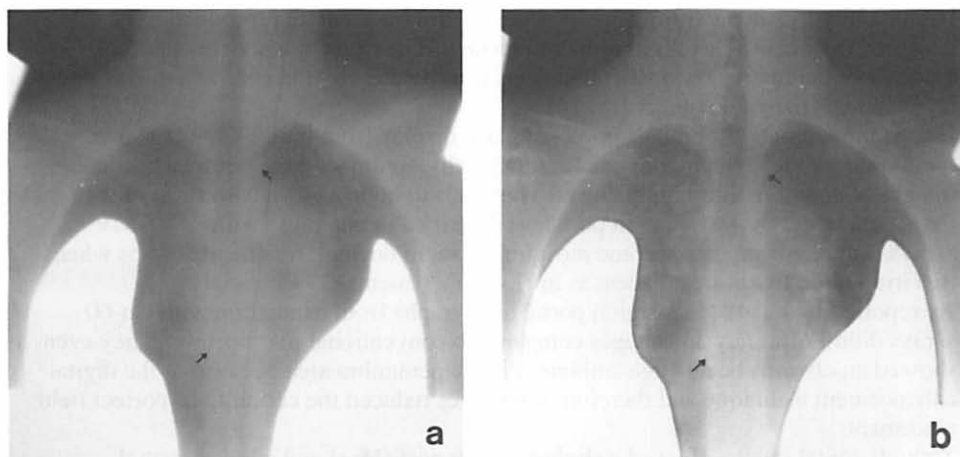


Fig. 3. 15 MV portal films of a patient with mantle field and lung blocks. The digital radiograph (b) yields better overall quality than the conventional film-screen image (a).

Table 3. Comparison of 9 digital (D) and conventional (C) portal radiographs of mantle radiotherapy (Co-60)

	D > C (%)	D = C (%)	D < C (%)
Contrast - air / soft tissue	0	93	7
Contrast - bone / soft tissue	7	89	4
Visualization - anatomical structures	11	81	8
Sharpness - anatomical structures	0	52	48
Position of shielding block - cranial	4	92	4
Position of shielding block - medial	18	78	4
Position of shielding block - lateral	4	89	7
Position of shielding block - caudal	0	89	11
Speed to define block position	8	92	0
Therapeutical value	4	89	7

Additionally 9 pairs of portal images of mantle radiotherapy with a Co-60 beam were evaluated. There was no advantage of digital radiographs in comparison with conventional ones (Table 3). Anatomical structures appeared sharper on conventional than on digital images.

Discussion

High quality treatment verification is necessary for an accurate reproduction of designed treatment schemes in radiation therapy. The exact visual delineation of anatomical landmarks on verification films is influenced by the contrast, the brightness level and the size of an object (15, 16).

Due to the separation of image processing and display from image capture digital luminescence radiography provides automatically optimized high contrast portal images of an optimal brightness level. This leads to improved visualization of soft tissue and bones in the radiation portal, as described in our study with 8 / 15 MV x-rays. These advantages become most important in difficult treatment set-ups when two irradiation fields are adjacent as in Hodkin's patients (17).

As reported by others (11), digital portal radiographs from irradiation with Co-60 x-rays didn't offer any advantages compared to conventional portal films. They even showed an obvious beam edge ambiguity in the penumbra area because of the digital enhancement technique and therefore sometimes reduced the certainty of correct field placement.

Though digital images showed a slightly higher noise level and a lower spatial resolution (sharpness of anatomical structures), this is not an important problem, because radiotherapy images are mainly contrast, and not resolution, limited. Of particular importance are the storage and retrieval advantages of digital images which allow for the possibility of image analysis as well as computerized comparisons of simulation and treatment fields.

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Dynamic Three-Dimensional Reconstructions of Colorcoded Duplex-Sonography Examinations

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Summary

Although Colorcoded-Duplex-Sonography has been proven to be a reliable technique for examining flow-changes and stenosis in peripheral vessels, it is still limited to 2D-views and -displays of the interesting vessel region. Therefore the impact of the flow changes caused by plaques etc. on real blood-speed and volume-flow within in the vessel is not detectable.

In order to overcome this detriment and to standardize examination procedures a system for timecoded three-dimensional scanning of interesting peripheral vessels has been developed.

Acquisition was performed in slice by slice technique, using a 7.5 MHZ transducer mounted on a linear-skidding and step-motor powered device. In order to provide time-equivalent Data-acquisition in each scan-position an ECG-triggering was used. The Images were transferred to an imaging system, reformatted according to the timecode, 3D-reconstructed and replayed in a cine-mode. Three-dimensional measuring of volume-flow and occurring flow-effects is possible and - with respect to the timecoding - four-dimensional calculations are available on the system.

First results and technical solutions for the system will be presented.

Introduction

The aim of the study was to develop a system to standardize ultrasound examinations of peripheral vessels and to provide a reliable and reproducible demonstration of pathologic findings within the vessel and the resulting blood-flow changes.

Although colorcoded duplex-sonography has been proven to be a reliable method of clinical routine to detect flow- and anatomical changes in peripheral vessels (1,2,3,4), it still depends on the experience of the examiner to estimate the impact of the findings on the blood-flow in the whole vessel.

We developed a system for 3D-scanning and -reconstruction of colorcoded duplex-sonography examinations to enable an reproducible overall view of flow-changes in peripheral vessels.

Method and Materials

a) System-configuration:

A standard color-flow imaging device (ACUSON 128XP) with ECG-triggering option and a linear 7.5 MHZ transducer were used for scans of peripheral vessels like the carotid artery. Acquired images were transmitted by analog video signals to an imaging system (Kontron-Mipron). The transducer was mounted on a linear maneuverable device powered by a step-motor. This device was controlled by a common Personal Computer, providing transducer positioning with a tolerance less than 0.1 mm (Fig. 1).

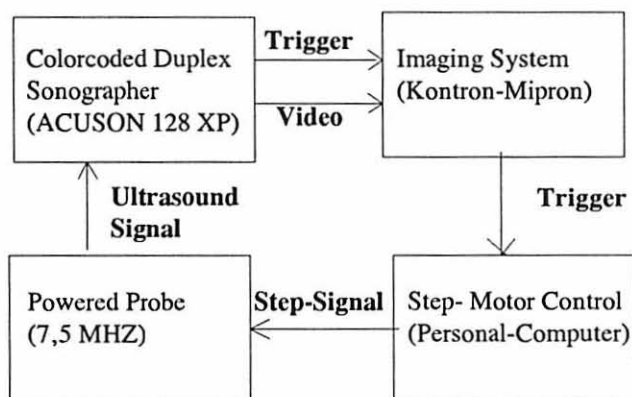


Fig. 1: System-configuration

b) ECG-triggering and timecoding:

Bloodflow-changes according to the heartbeat require timecoding of the acquisition in each slice-position. Depending on the scanned vessel, images were taken with increasing trigger delays on the R-peak of the electrocardiogram, using stepwidth between 50 and 100 msec. Therefore the resulting images are both time- and scanposition-coded and could be reorganized after transmission to the imaging system to time-equivalent-data-blocks (Fig 2,3 and 4).

c) 3D-reconstruction:

In a first step we used the color-video signal instead of the raw-ultrasound-data for the 3D-reconstructions. The analog color-signal was divided into the basic colors red, green and blue before reconstruction using a combined maximum-intensity- and surface reconstruction algorithm based on volume-rendering and voxel-modelling with a calculation-depth of 16 bit per pixel. The lower 12 Bit were used for the greyscale

of the video image and the upper 4 BIT to encode the basic color of the pixel (red, green, blue). Combined with the timecode this procedure enables to separate each pixel from the data-set according to its color for separate 3D-reconstructions and 3D-measurements. The resulting 3D-reconstructions are still timecoded and - replayed in a cine mode - provide a view of the flow dynamics within the whole scanned vessel area.

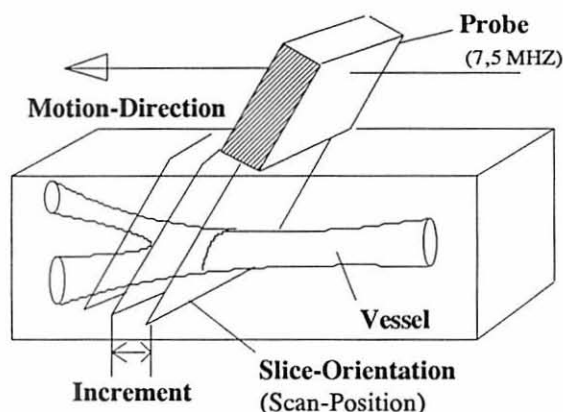


Fig. 2: Step-Motor powered Probe- and Scanpositioning

Results

Examinations were performed using the system for scanning carotid and femoral arteries. Especially scans of the carotid artery required high timeresolution with 50 msec or less steps for the increasing ECG-trigger-delay to acquire the rapid flow-changes in the vessel between 50- and 150 msec after the R-peak. But in comparison 100 msec steps were sufficient to detect flow changes in the femoral artery. Depending on the used trigger stepwidth and the slice thickness an original data set consists of up to 1200 images. Colorseparation, reformatting and 3D-reconstructions are much more time-consuming than static 3D-displays of either CT or MRI-images. The limited frame-rates (max. 18 frames/sec) of common color-flow ultrasound systems force to use more than one heartbeat for acquiring the whole triggered image-cyclus in a scanposition. On the other hand linear high-resolution probes (7.5 MHz) with axial scan orientation and small slice increments (1 or 2mm) are needed to provide high spatial resolution of the three-dimensional display. Using the color-separation and -value it is possible to calculate real blood-speed as well as volume flow.

Discussion

The advantage of 3D-reconstructions for demonstrating pathologic findings has been shown in several studies for MRI and CT images (5,6,7). But compared to this static techniques 3D-displays of the rapid changing blood-flows in peripheral vessels enable to use real additional views of the whole interesting area for the diagnosis. Although

comparable in some details to recent introduced real-time interactive color-flow MRI (8), color-coded-duplex-sonography and 3D-reconstruction offer an easier way to acquire and display anatomical- and functional pathologic findings of the whole interesting vessel region. Although the reconstruction time and the probe must be improved, we think that 3D-reconstructions of color-coded-duplex sonography examinations provide a new and additional aspect for ultrasound examinations of peripheral vessels.

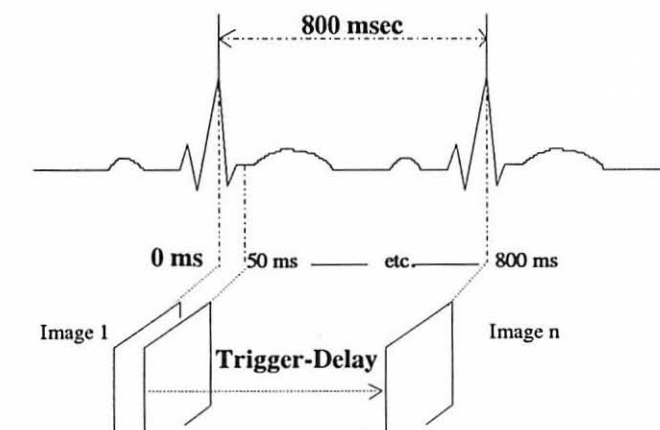


Fig. 3: In each Scanposition images are taken with increasing Trigger-Delays (Stepwidth 50 or 100 ms)

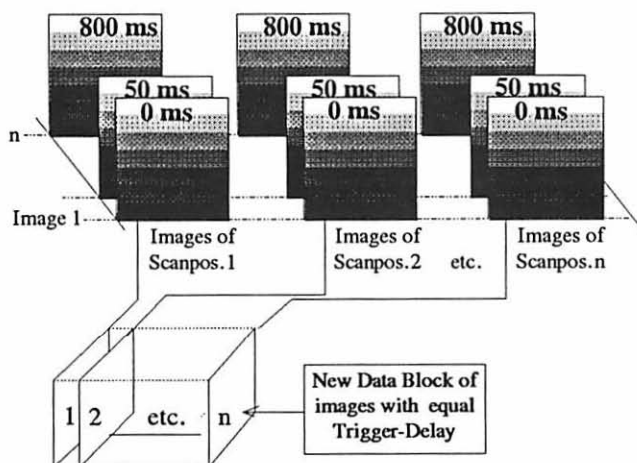


Fig. 4: All images are rearranged according to timecode (Trigger-Delay) and position (Scanposition) before 3D-reconstructed.

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Education and Decision Support in Radiology: Authoring Using a Building Block Architecture

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Radiologic practice requires access to multiple forms of data and knowledge—text, images, video sequences, animations, lists, database records, and results of analytic and inference procedures. Organization and view of this content depend on the problem or task being carried out, e.g., clinical interpretation, consultation, tutorial learning, query, or clinical skill building. The Decision Systems Group has been developing authoring tools that support construction of application views from building blocks of information resources. Information resources can be retrieved and shared among different contexts (i.e., "repurposed") to allow clinical, educational, and other applications to be developed from the same pool of resources. Based on this approach we have been working on various radiologic education and decision support applications. Examples include: ETF (Electronic Teaching File)—a hypermedia case presentation format using diagnostic-quality images and query-based retrieval; GuideIns—a clinical algorithm format used as a decision aid for clinical workup strategy and as a means of providing educational guidelines and assistance in assessing quality of care, particularly concerning imaging procedure utilization; and Gamuts—a hierarchical collection of disease findings and differential diagnoses with associated images. A related task, to facilitate management of the diverse archived information resources used in the above, is our work on taxonomic description of image content as part of the Unified Medical Language System project of the National Library of Medicine.

Introduction

Management of health care information requires access to multiple forms of data and knowledge. The patient information with which a clinician deals includes text, numeric data, images, video sequences, and sounds. Knowledge may be in the form of compiled lists, reference databases, textual descriptions, or analytic and inference procedures.

Managing the wealth of image data, in all its many forms, has become an important function of every radiologist and radiology department, both for clinical needs (storage, retrieval, access, correlation) and for education, decision support, and research (personal files, lectures, research, skill building). Although images remain central to the practice of radiology, the information used and produced by radiologists also exists in other formats. Structured text (radiographic reports, consultations), database records (time-oriented reports, summaries), complex data models (workup strategies, guidelines), and didactic material (reviews, differential lists, gamuts) are all important to radiology practice and education.

Organization and view of radiographic medical content depends on the problem or task being carried out, e.g., clinical interpretation, consultation, tutorial learning, query, or clinical skill building. Although each of these tasks may require a unique perspective and subset of critical information, they all share basic data elements made up of the multimedia formats noted previously. Applications designed to support clinical and educational activities require the ability to incorporate these multimedia content elements [1,2,3]. At the Decision Systems Group (DSG) we are developing and evaluating techniques that facilitate sharing and "repurposing" (or "multi-purposing") of data and knowledge among applications [4]. Authoring tools that support construction of application views from building blocks of information resources [5] are a central aspect of our work.

Embedded vs. independent content

Since knowledge acquisition is one of the greatest obstacles to the creation of knowledge management and educational systems [6], research on the sharing of multimedia content and medical knowledge [7] has become imperative. Frequently, content developed for one application cannot be easily redirected or repurposed for use in another application, even if both were created within the same authoring environment, since the content is often embedded in the application itself, rather than retrieved from an external source. The problem caused by inaccessibility of available content are compounded by the assortment of incompatible authoring environments and the variety of system and hardware platforms in use. Although these issues have made sharing of information difficult, systems that support content repurposing boost authoring productivity. For example, the DSG is creating educational applications that allow student-directed browsing of supporting material in case-based learning modules [8]. This material exists in a wide array of media types and formats that range from text-based dictionary descriptions to image collections depicting classic findings. Although this material may be developed for individual cases, it subsequently becomes available for all cases in the library, as well as for use in quizzes, tutorial material, or other applications.

Authoring Tools

We have addressed the above needs by a new software architecture called DeSyGNER (Decision Systems Group Nucleus of Extensible Resources) that treats applications as being composed of (a) information resource "building blocks", and (b) compositions of these information resources to provide particular user interface and interaction paradigms. Information resources can be text, numeric data, images, sounds, motion sequences, and so forth. Compositions are the ways in which these resources are reorganized, e.g., by connecting them via hyperlinking, by laying them out spatially as "page layouts", by organizing them hierarchically as outlines or "book layouts", by indexing them for query-based access, and by branching conditional organization as in protocols, tutorials, and flow charts. A composition such as a page layout, outline, flow chart, or hyperlinked content group, once created, also becomes an available building block, allowing this methodology to be applied recursively to construct very powerful and elaborate applications.

The architecture for providing the above capability relies heavily on object-oriented design. Each information resource is treated as a persistent object called an "entity", as is each composition. Classes of information resources and compositions allow

one to create a set of customized templates or "shells" for authoring of applications. Since all needed entities are available as building blocks, direct manipulation authoring without programming or scripting can be carried out easily. A "kernel" provides services that we expect will ultimately become part of the host operating system. The kernel maintains entities and can create new ones, can locate existing entities, supports access to them, and controls versions of entities when changes affect incoming links.

Network Environment

The object oriented approach of DeSyGNER is intended to enable information objects to be network-resident and to be accessed via interprocess and interprocessor communication rather than only via object messaging within a single application. Further extensions to this architecture are needed to ensure that available network resources can be identified and located, and that objects can be accessed on a variety of platforms via standard messaging protocols. These extensions are a major aspect of our on-going development.

Applications

Electronic Teaching File (ETF) is a continuing project using the DeSyGNER authoring environment to create radiology teaching files in an electronic format. Using DeSyGNER authoring tools, the radiology staff and fellows may integrate actual patient images, textual material, scanned gross and microscopic pathology specimens for clinical correlation, scanned radiology films using modalities that are unavailable in digital form at our institution (plain films, ultrasound), and other scanned graphic material. Authors may even include video sequences. Teaching file "compositions" are documents that utilize hyperlinking to move from one document to another, maintaining the author's perspective on the presented material. Authors may create electronic question/answer series, demonstrate classic findings, explain a radiographic technique, or lead the user through an unknown case. Material may be presented in more than one way, perhaps using a portion of an image from an ETF case to demonstrate a classic radiographic finding in a tutorial.

Actual MRI and CT patient cases are selected for the teaching file by the radiologist at any point after imaging is completed. Using DECRad, the radiology information system at Brigham and Women's Hospital, a clinician can tag a case as "interesting". Interesting cases are then automatically identified prior to departmental archiving and are transferred across the departmental Ethernet backbone to the ETF workstation for processing into DeSyGNER's "zoom" format for high-resolution viewing [9]. Images in this format can be incorporated into any DeSyGNER-based application.

For ETF cases the case presentation is constructed according to author preferences using case "templates" of "page layout" compositions that may reflect the standard paper-based teaching file format or may provide display techniques unique to the hypermedia environment. Relevant images are selected from the patient study by viewing image arrays; the image is then cropped, gray-scale modified, and annotated with overlays as necessary. "Hyperlinking" is used to connect to further detail about a case, often providing in-depth explanations, references, or access to related information (see figure 1).

Indexing of the cases is presently limited to keyword associations and ACR coding. As noted below, (see UMLS work) we are interested in basing the coding and retrieval of image-based information on a more robust understanding of the concepts used to describe images.

Gamuts and Image Galleries constitute another application format in use at the DSG wherein we may construct outlines of categories of findings with sublists indicating diagnoses to be considered, possibly with descriptions or rankings. This is the familiar "gamuts" format. Attaching images to the sublist elements provides immediate access to a gallery of images showing a particular finding in various diseases. The inverted outline, organized by diagnosis and with sublists characterizing the range of possible findings for each, may be similarly annotated by attached images.

Two composition methods of DeSyGNER make this capability easy to achieve: Using "book layout", we can organize content elements hierarchically in outline or electronic book format, which a user can selectively collapse or expand for viewing. The second composition method supports construction of "proxies" and "proxy grids". Proxies are thumbnails of images, and proxy grids are panels of such proxies. Selecting a proxy causes the actual image to be retrieved and displayed. Not only images but proxies and proxy grids can be placed anywhere in an outline hierarchy of a book layout composition.

Guidelines for Workup and Management. An increasing role of the radiologist is to provide consultation, not only about image interpretation but also about the next steps in patient workup and management. This is especially necessary given the growing concern with medical technology costs and the emphasis on cost-effective patient care.

We have had long interest in the use of multimedia formats for presenting patient workup strategy to facilitate clinical decision making [10]. We have also developed dynamic representations of flowcharts that can be collapsed or expanded, depending on focus of interest of the viewer, which is another composition method of DeSyGNER [11]. Clinical guidelines can be expressed in flow chart or algorithm format with explanatory material, references, discussion, or examples of results provided as expansions of any of the boxes in the flow chart via hyperlinking.

We are exploring the use of guidelines, not only as educational resources to aid decision making, but also to structure clinical data collection, e.g., radiologic reporting, and the entry of physician orders. With respect to the latter, our hope is to eventually allow a guideline to be reviewed as part of the order entry process, to capture the pathway selected by the clinician user as a description of the patient, and to automatically generate a request to radiology for the procedure indicated in the algorithm.

Other Applications We are also applying DeSyGNER to a variety of other application types. Query-based search is being developed in conjunction with a natural-language query interface called SAPHIRE [12] that matches terms to concepts, to enable information resources to be retrieved. Tutorials are being

developed using hyperlinking and page layout composition methods, one application currently being in the area of abdominal imaging. Quizzing and self-testing applications are also being developed, for internal use in conjunction with the Radiology Information Systems Consortium (RISC)'s DRILL project.

UMLS work

As the amount of image-based information increases, organized access to the individual elements becomes increasingly important. Coding image content has been a difficult task, primarily due to the range of the information contained in an image. Images can be described both in abstract terms such as "toxoplasmosis of the CNS" or in a specific way such as "ring-enhancing lesions in the parietal lobe on head CT". A system that allows the user to search a database using a concept at one level of abstraction but retrieve images or documents that contain images that were coded using concepts at another level of abstraction will require an understanding of how specific image attributes can be abstracted to describe more complex radiographic findings. As part of our work with the National Library of Medicine's Unified Medical Language System® project (UMLS™), we are investigating a semantic representation of concepts used in radiographic image description. This representation is based on an image "observation-interpretation continuum" where findings are recursively made up of more specific image attributes. Once in place, this will allow a user to search a database of image-based information to retrieve images and documents matching the query on many levels.

Conclusion

As demonstrated by the examples in this paper, radiologic information content may be used in a variety of application formats to provide a wide range of education and decision support capabilities. This process can be greatly facilitated by an architecture in which the information resources are developed and maintained separately and then incorporated into applications through composition methods that support particular user interfaces and interaction paradigms. This enables the variety of information resources and composition methods to grow and develop independently. As this process occurs, capabilities for authoring of new applications become increasingly enriched, the effort becomes substantially easier, and the ability to leverage the work of others and do collaborative development is enhanced.

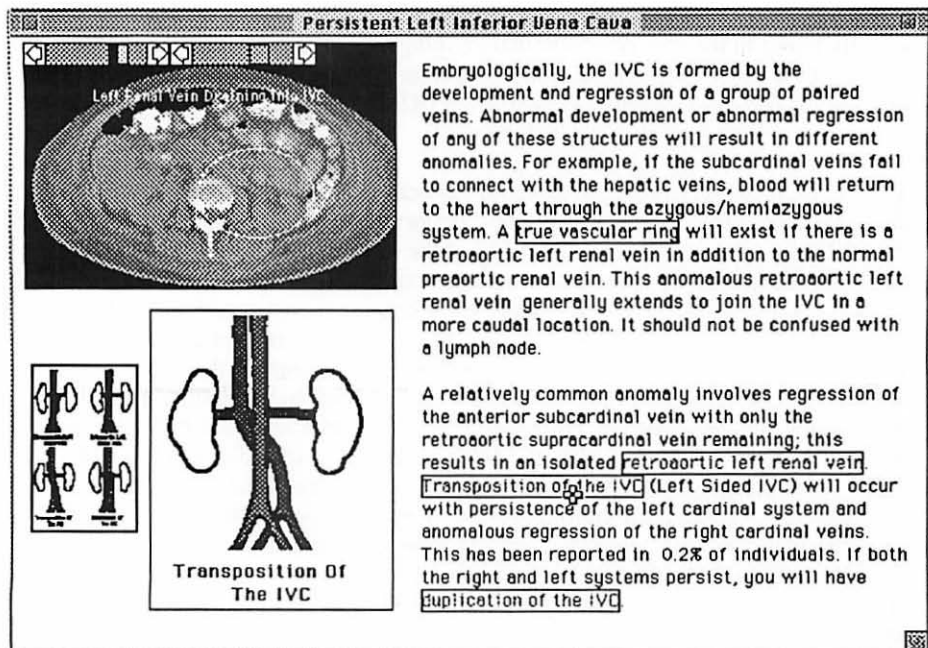


Figure 1. An example of an Electronic Teaching File composition or document. This example uses text, a full-resolution "zoom" image, graphics, and hypermedia buttons (boxed text) which change the graphic to demonstrate the indicated lesion.

Acknowledgements

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Interactive Data Processing for Magnetic Resonance Imaging: Application to Diffusion and Perfusion Imaging

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I. Introduction

New magnetic resonance imaging (MRI) techniques now provide data on tissue microstructure and function. Diffusion imaging, for instance, noninvasively reveals information regarding the mobility of water and other important metabolites in tissues at the microscopic, cellular level [1]. Blood microcirculation (perfusion) may also be evaluated by MRI using different approaches [2]. These techniques commonly require intense pixel-by-pixel manipulations of large numbers of images according to complicated models. Unfortunately, however, most widely used radiology image processing programs are inadequate for these purposes.

In order to satisfy our needs, we have therefore written an interactive image processing program for MRI data, which is not only of general interest for functional MRI, but is also specifically engineered for diffusion and perfusion imaging. For example, the above methods derive parameters of diffusion and perfusion from the decay curves of appropriately sensitized MRI signals using a nonlinear iterative fitting algorithm [1]. Our program attaches this algorithm to a convenient interface facilitating the study of diffusion and perfusion within an entire image or region of interest. Dramatic images depicting these physical parameters may be generated. Another algorithm combines diffusion images to explore anisotropic diffusion. Several perfusion MRI techniques [2] are also supported.

II. Implementation

The program is coded in Interactive Data Language (IDL¹). IDL is gaining wide acceptance for research applications and provides many conveniences for sophisticated software development. PostScript² compatibility and an extensive library of relevant routines for defining regions of interest, changing color tables, and so on are exceptional benefits. Since IDL lacks support for stand-alone executables, however, the program cannot be utilized on systems without IDL installed. Converting it to another language, such as C, for greater portability may be anticipated.

¹IDL is a trademark of Research Systems Inc.

²PostScript is a trademark of Adobe Systems

The program operates on Sun³ Workstations under UNIX⁴ and X Windows⁵. Hard copy output is produced on a PostScript laser printer.

III. Features

Most input tasks are performed with the three-button mouse. The left button is generally used to select from the main menu, image panel, calculator keypad, and so on. When the buttons serve differently, appropriate information is given. For example, "LMB: Mark Pt MMB: Erase Pt RMB: Done" describes the left, middle, and right mouse button while defining a region of interest.

Images created by the program are given straightforward extensions for identification purposes. For example, ".dif", ".per", and ".ani" respectively correspond to diffusion, perfusion, and anisotropic diffusion images. Files created by the program are similarly labeled.

Since multiple clinical and experimental MRI units (Signa 1.5T, Omega 2T, and 4.7T)⁶ are used in our department, the program automatically recognizes several image formats. This feature can easily be expanded to accommodate additional formats.

A built-in UNIX directory browser makes locating particular files more efficient. Also, the program manages its own windows while still allowing UNIX to execute additional processes via multitasking.

IV. Functions

The main menu identifies operations that can be selected with the mouse...

Next/Previous Img: Displays the next/previous image.

Img Panel: Displays images in a 4 by 4 array.

Img Processing: Displays the image processing submenu. This submenu offers smoothing, edge enhancement, and an image calculator. The image calculator evaluates infix mathematical expressions for images. For example, the expression "(RAW:i.001+RAW:i.002)/2" produces an average image from raw images named i.001 and i.002. (This calculator was programmed using principles discussed in [3].)

Profile: Plots pixel value vs. position along a specified line through an image.

Cine Loop: Displays raw images as frames in a movie.

View Raw/Calc Imgs: Displays raw/calculated images.

Export Screen: Allows images to be annotated and saved in a format suitable for export to either a Signa MRI unit or MacIntosh⁷ personal computer.

³Sun is a trademark of Sun Microsystems

⁴UNIX is a trademark of AT&T

⁵X Windows is a trademark of the Massachusetts Institute of Technology

⁶Signa & Omega are trademarks of General Electric

⁷MacIntosh is a trademark of Apple Computer

ROI: Allows up to 12 regions of interest to be defined, rotated, translated, or deleted.

Analyze ROI: Plots the appropriately sensitized NMR signal decay within a region of interest and uses nonlinear iterative fitting to determine corresponding physical parameters as suggested in [1]. Results contain a calculated signal amplitude, diffusion coefficient, perfusion fraction, and pseudodiffusion coefficient. A perfusion imaging technique using dynamic imaging of contrast agents is also available [2].

Show ROI: Displays regions of interest.

Do IVIM: Physical parameters are determined for every pixel rather than just regions of interest as in Analyze ROI. Signal amplitude, diffusion coefficient, perfusion fraction, and pseudodiffusion coefficient images are thereby produced, according to the intravoxel incoherent motion (IVIM) model [1].

Do Aniso: Produces a diffusion anisotropy image [1].

Do Perfusion: Produces a perfusion image [2].

Modify Col Tbl: Allows the grey scale or color palette to be modified for images.

New Raw Imgs: Allows raw images to be loaded.

New Session: Begins a new MRI data processing session.

Save Session: Allows current work to be saved.

Load Session: Restores regions of interest, raw images, calculated images, color tables, and other variables from a previous work session to memory.

Quit: Exit

<Control-P>: Prints the screen.

V. Acknowledgements

The authors gratefully acknowledge Drs. James Pekar, Geoff Sobering, and Robert Turner for their help and comments in writing the program.

VI. References

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Comparison of Fast Scan and Conventional Spin Echo Imaging Techniques in Post Processed MR Imaging of Uterine Fibroids

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ABSTRACT

A Medical imaging workstation (Allegro Workstation ISG Technologies Inc. Toronto, Ontario) is used to post process MR images of the pelvis. These can provide gynecologists with detailed pre and post operative imaging. The workstation has been used elsewhere to post process spine, dental, and cranial images to depict anatomy and pathology. MRI has been shown to provide superior visualization of uterine fibroids and their relation to the endometrium. When MR imaging is combined with post processing, the resultant images not only provide for the simultaneous visualization of the anatomy in the coronal, sagittal, and transverse plane but allow "melt through" to visualize the anatomy at any orientation desired. High resolution capabilities of the workstation in combination with the new fast spin echo techniques provide more accurate post processed MR images that give high quality 3-D visualization of uterine fibroids and pelvic anatomy. This is demonstrated with examples of pre and post operative MR images of the pelvis using both conventional and fast spin echo techniques.

Key Words: Fast Scan, Computers, Post processing, MRI, pelvis, fibroids.

INTRODUCTION

CT imaging revolutionized radiologic imaging by depicting anatomy in a way that is not available with conventional radiography. MRI takes this one step farther. A great advantage of MRI is its ability to image in the sagittal, coronal and transaxial plane. Structures that meander through the imaging plane on the transaxial slices can now be visualized in greater detail by depicting them in planes that better illustrate their relationship to surrounding structures. For any given case, it is impractical to acquire images in all planes and all weighting techniques that are now available with MRI. This would involve long acquisition times and hinder patient throughput, as well as producing redundant information. Not all weighting techniques and planes are required. The sequences required depend on the pathology, clinical setting and the visualization required by the referring physician. Since multiple sequences are limited by time constraints, motion, and anatomical orientation, basic minimal sequences combined with a contiguous data set for post processing provide an efficacious solution to the imaging dilemma of the pelvis.

Post processed MR and CT images have demonstrated their ability to improve the visualization of the multiple images and planes that can now be obtained. Utilization of multidimensional workstations to aid neurosurgical, craniofacial, and dental surgery is becoming more common place [References (1),(2)]. CT and MR imaging of the cranium and facial area provide remarkable resolution due to the fact that this area can be easily secured to minimize motion. Surgeons can refine their surgical approach and greatly decrease the incidence and severity of complications to invasive procedures because of the workstations' ability to show specific anatomy and abnormal structures in a correct anatomical representation. These same advantages are now available for pelvic imaging as a result of fast spin echo techniques.

A deterrent to imaging the pelvis is the long scan times and resultant artifact from patient motion. This paper demonstrates how fast scan MR images and post processed images can provide the radiologist with a clearer depiction of uterine fibroids and their relationship to the endometrium. The surgeon can determine whether a fibroidectomy or hysterectomy should be performed once the relationship of fibroids to endometrium is determined. This is achieved with: 1) Three dimensional interactive representation of the pelvis. 2) T2-weighted images with times that are short in duration and which provide excellent contrast detail on the grey scale 3-D reconstruction images. 3) Simultaneous images in multiple planes.

MATERIALS AND METHODS

The Allegro workstation system used for post processing MR images consists of a High resolution image display with dual 1024 x 1024 x 8 frame buffers, 8 parallel TMS320C25 DSPs (digital signal processors), a 32 Mbyte image memory and 1 Gigabyte of disc storage. The system has the ability to read MRI and CT data from 50 different scanners which is transferred via magnetic tape. The workstation is interfaced to a laser imager, a video recorder, and a thermal color printer. The system uses a Unix based operating system. The software utilizes interactive 2-D melt through, highspeed 3-D reconstruction and interactive 3-D display. The MR images are obtained with a GE Signa 1.5 Tesla MR scanner equipped with advantage 4.7 software MRA and fast spin echo. (G.E. Medical Systems, Milwaukee, Wisconsin).

Imaging was performed to determine the optimal parameters that would best visualize the female pelvic anatomy and demonstrate the relative location of uterine fibroids on the post processed images. The ease of post processing was also evaluated. The patients chosen for this evaluation represent patients scheduled for hysterectomy or fibroidectomy surgery depending on the extent of uterine involvement. Contiguous T2-weighted CSE (conventional spin echo) sagittal and axial slices were obtained through the pelvis. Axial and sagittal FSE (fast spin echo) T2-weighted sequences were also evaluated for ease of post processing and for imaging accuracy.

Each individual MR image loaded into the workstation has to be segmented. A threshold (based on signal intensity) or outline of a desired structure is created and a "seed" is placed over it (Figure 1). The seed will be carried from frame to frame maintaining the threshold that was created.

The dermis is segmented separately to accurately show uterine, ovarian, and fibroid tissue with gray scale representation in relation to the surface anatomic landmarks. The area within the dermis is then segmented to provide a gray scale background for the pelvic structures. Since all structures will not segment evenly, a draw command is used to "paint in" all unsegmented areas (Figure 2). All areas that are of pathological and anatomical interest are now segmented individually and assigned a color. The Allegro system only allows for three different colors to be displayed at one time and only those areas of interest that show the important structures or pathology in question are given a color designation. When all segmentation areas have been completed, the images are reconstructed. The grayscale background portion of the segmentation is reconstructed excluding the segmented structures inside the grayscale segmentation. The structures that can be segmented in this area include the uterus, and/or endometrium, ovaries, and other pathology.

The 3-D reconstructed data is reviewed in several ways: 1) Real time rotation to display the anatomy at any angle. 2) Visualization of all or any individually segmented area. These segmented areas can be disarticulated from each other to expose hidden surfaces. 3) Segmented structures that overlap or surround anatomy in question can be made translucent to show underlying anatomy while maintaining an outline of the surrounding structure. 4) Cutting planes are used in three orthogonal planes to simulate the visualization at surgery.

CASE STUDIES

CASE 1

The images of the first case were obtained with conventional spin echo techniques. T1-weighted axial and T2-weighted sagittal images were obtained. Parameters were TR=600, TE=16, matrix=256x128x2nax,thick=4 mm, gap=0, acquisition time = 7 minutes for the axial images (3a,b) and TR=2500, TE=20/80, matrix=256x192x1, thick=5 mm ,gap=0 ,acquisition time= 9 minutes for the sagittal images (3c,d). The data was transferred to the Allegro system. Figures 3a,b and 3c,d demonstrate the segmentation of the dermis with the grayscale interior. The uterus is totally replaced with leiomyomas its rendition is depicted by the green colored structure. Note the ripple effect on the abdominal surface due to respiratory motion. The uterus also appears jagged on the rendition from axial images, Figure 3a,b. This reflects the discontinuity that is produced when the segmentation is done on thick slices from which the data is then interpolated. The rendition from the sagittal images has less ripple effect from respirations and the uterus is more uniform. Note that the best appearing surfaces are those that represent the acquired plane (axial for Figure 3a,b and sagittal Figure 3c,d). This is due to the fact that the other planes are generated from an isotropic data set that was obtained by the interpolation algorithm used. This patient underwent a total hysterectomy. No distinct endometrium was visualized on the MR images.

CASE 2

This patient underwent a transvaginal fibroidectomy. Pre-operative images in Figure 4 a,b,c were obtained with conventional spin echo techniques. TR=2500, TE=30/80, matrix=192 x 1nex, thickness=5 mm, gap=2.5 mm, acquisition time= 9 minutes. There is a fibroid in the anterior myometrial wall (arrow) with some associated increased signal indicating some degeneration of the fibroid (curved arrow). Post-operative images were obtained with FSE techniques (Figure 5a)(TR=3700,TE=96,matrix=256 x 256 x 2nex, thickness=3 mm, gap=0) and segmented to produce the 3-D renditions in Figures 5b-d. These depict the residual fibroid bed following transvaginal resection. The endometrium is less distorted and the area of increased signal representing degeneration is decreased in size. The post-operative findings are well depicted on the higher resolution FSE images (Figure 5a). The corresponding 3-D reconstructions provide more detailed depiction of the post-operative bed. (Uterus is green, endometrium is red.)

DISCUSSION

Uterine fibroids can be demonstrated in relation to the normal anatomy using a grayscale segmentation technique. Pelvic anatomy is better depicted with the use of FSE (fast spin echo) techniques which provide less motion artifact with higher resolution on the T2-weighted images than previous conventional spin echo techniques. (cf: Figure 5 to Figure 3). The T2-weighting offers a grayscale background with which the segmented fibroids can be related to the uterus. T2-weighting is more useful in pelvic imaging when the uterine layers are to be visualized.

Segmentation is more difficult in the axial plane than in the sagittal plane when segmenting the uterus. The axial image segmentation provides more pleasing renditions in 3-D reconstructions due to the higher resolution in the imaging plane (axial). This is also the plane more familiar to the radiologist and surgeon. Segmentation of sagittal images may be more appropriate if the pathology to be demonstrated lies with a longitudinal axis in the axial plane and the relationship to anatomy in the sagittal plane is required (This is seen in Figures 3c,d).

Imaging the pelvis with contiguous slices that can be post processed to produce 3-dimensional reconstructions with little or no motion artifact is due to the considerable decrease in acquisition time afforded by FSE techniques.

CONCLUSIONS

This preliminary evaluation demonstrates that FSE(fast spin echo) techniques now allow efficient imaging of the pelvis with little or no motion artifact.3-dimensional reconstruction techniques can be used to portray pelvic pathology in relation to pelvic anatomy with reasonable accuracy. The present examples illustrate cases with uterine fibroids but this can be extended to other pathologies in both the male or female pelvis. Sixty slices can be acquired with 5 concatenated acquisitions in 6 minutes using a 256 x 256 x 2nex matrix compared to the 40 slices obtained with 2 acquisitions with a 256 x 192 x 1nex in 9 minutes using conventional spin echo. The parameters used for these preliminary scans that provide reasonable 3-d reconstructions would have required over 60 minutes if conventional spin echo techniques were used.

Acknowledgements: We would like to thank Robert Gomez, Chief MR tech at Mountain Diagnostics, for his help in acquiring the images reconstructed in this report.

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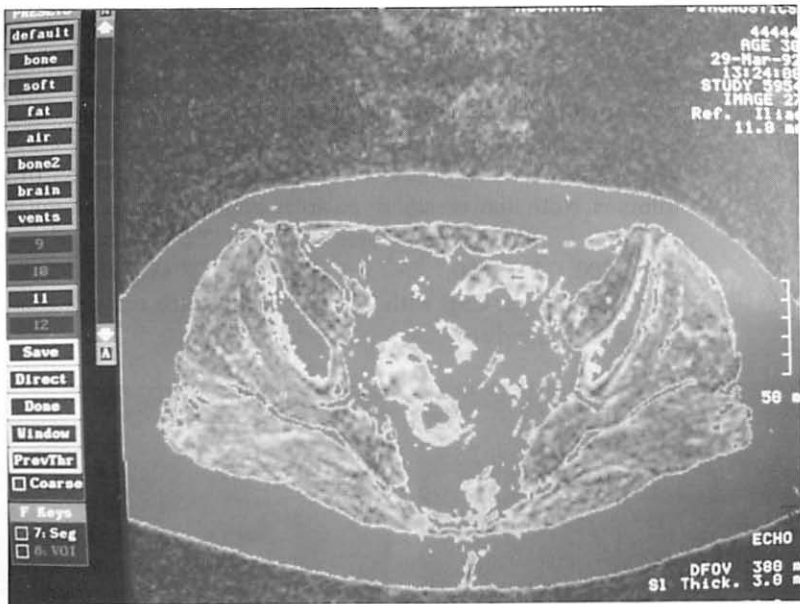


FIGURE 1: Threshold outline based on signal intensity (purple). Axial image of the pelvis with segmentation of dermis.

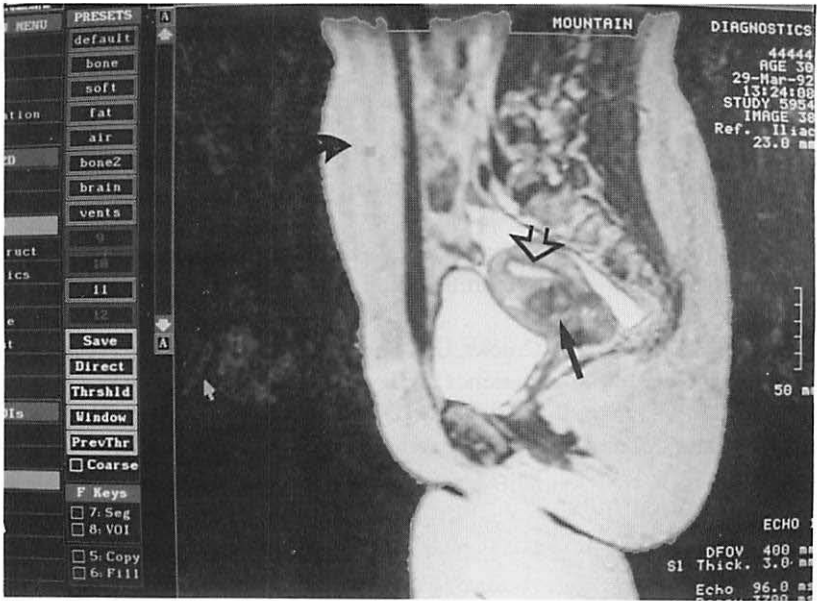


FIGURE 2: Yellow seed (curved arrow) inside of totally segmented pelvis after draw command. Fibroid(straight arrow), compressed endometrium(open arrow), see Case 2.

FIGURE 3: Patient with total replacement of uterus with fibroids. Hysterectomy performed after imaging. Uterus is green.
(a,b) reconstructed axial T1-images with parameters of TR=600, TE=16, Matrix 256 x 128 x 2nex, 4 skip 0, acquisition time = 7 minutes. Note iliac crest(curved arrow) and left acetabulum(straight arrow).
(c,d) Reconstructed Sagittal T2-images. Parameters TR=2500, TE 20/80, 250 x 192 x 1nex, 5 skip 0, 9.2 minutes acquisition time. CSE with 22 slices. Note some early degenerative changes in the discs.

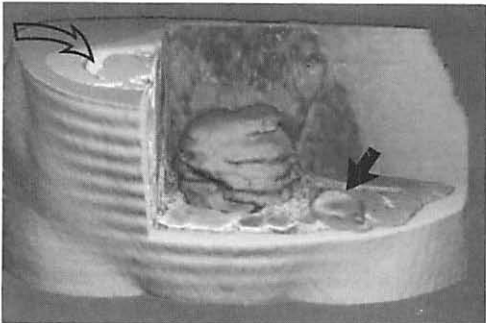


Figure 3a.

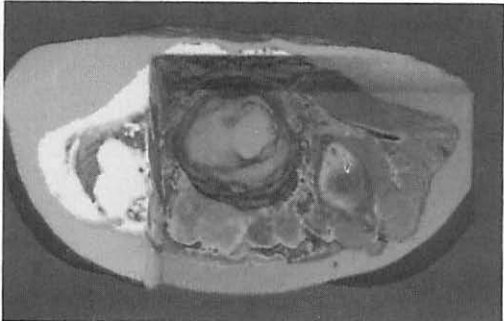


Figure 3b.

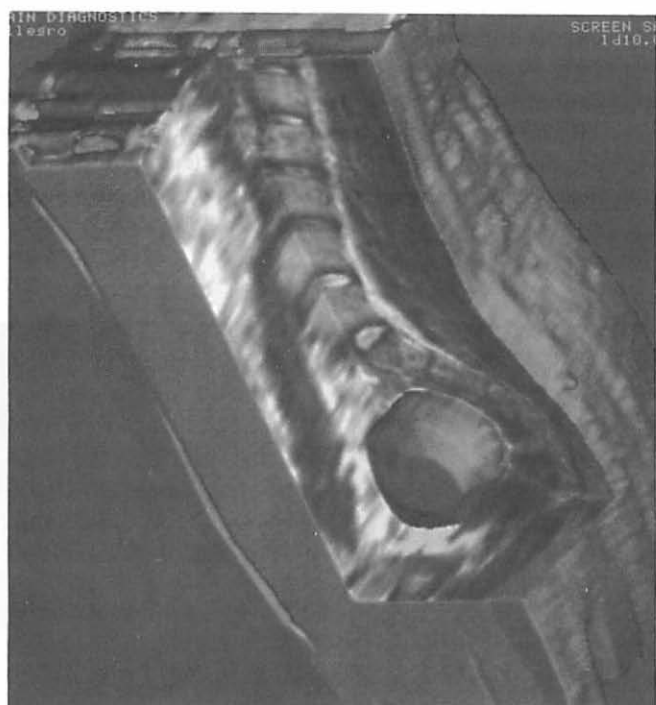


Figure 3c.

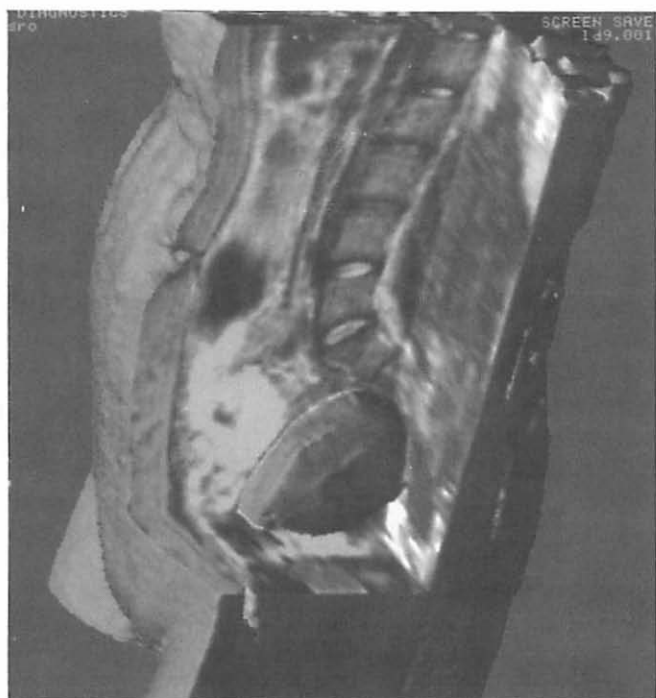


Figure 3d.

FIGURE 4: Patient with uterine fibroid. (A, B & C) T2-pre-operative images TR=2500, TE 30/80, 5 skip 2.5, Matrix 256 x 192 x1nex, 9 minute acquisition time. CSE with 22 slices. Fibroid(straight arrow), degeneration changes(curved arrow), endometrium(open curved arrow).

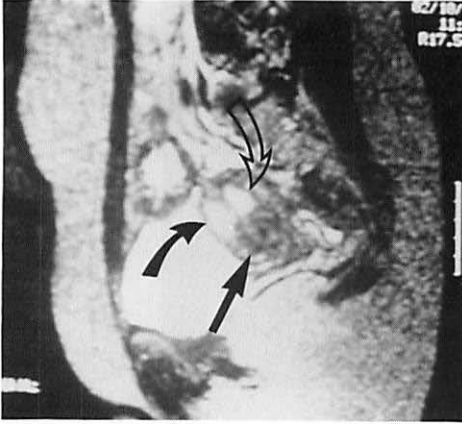


Figure 4a.

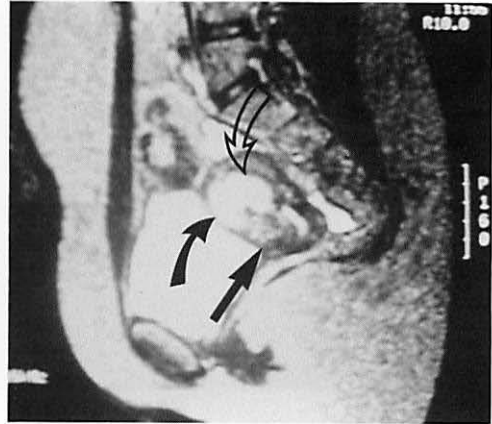


Figure 4b.

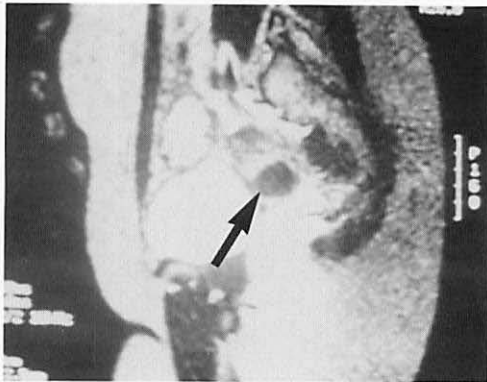


Figure 4c.

FIGURE 5: Post-fibroidectomy of patient in Fig# 4. (A) Post-operative image. TR=3700, TE=96, 256 x 192 x 2nex. Matrix=256 x 192 x 2nex. 3 skip 0. Reconstruction from sagittal sequence in (a). (c,d) Reconstruction from axial acquisition with parameters of TR=4000, TE=96, 3 skip 0, 256 x 256 x 2nex. 60 slices with 5 concatenated acquisitions in 6 minutes. Post operative fibroid bed(open arrow), residual perifibroid changes(curved arrow), endometrium(curved open arrow/red), uterus(green), note: fluid in cul-de-sac(white arrow).

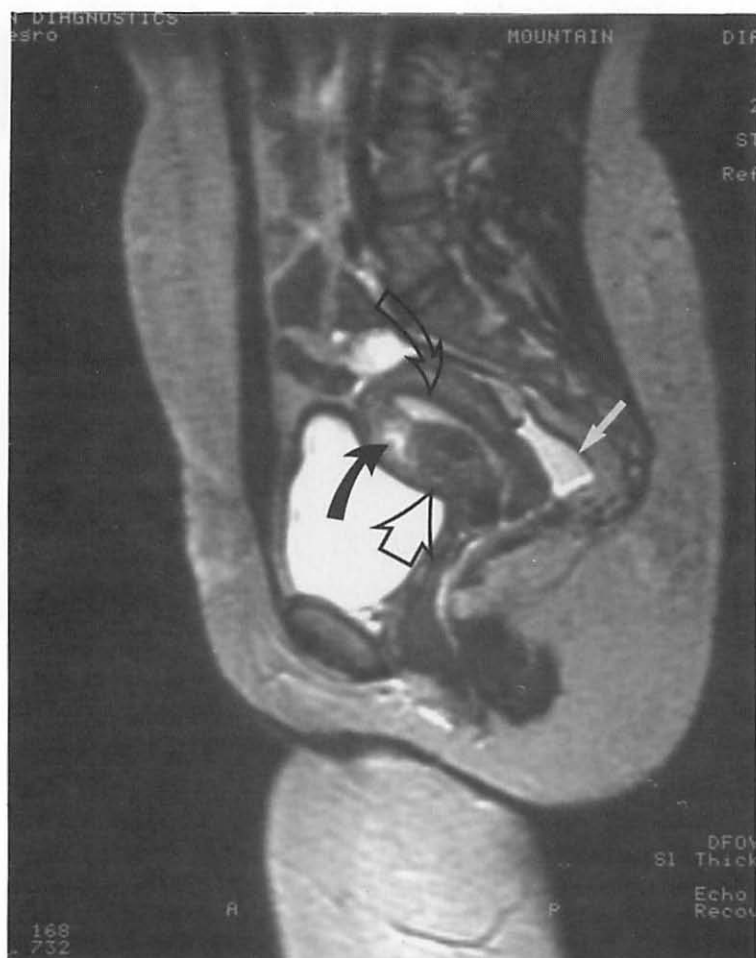


Figure 5a.

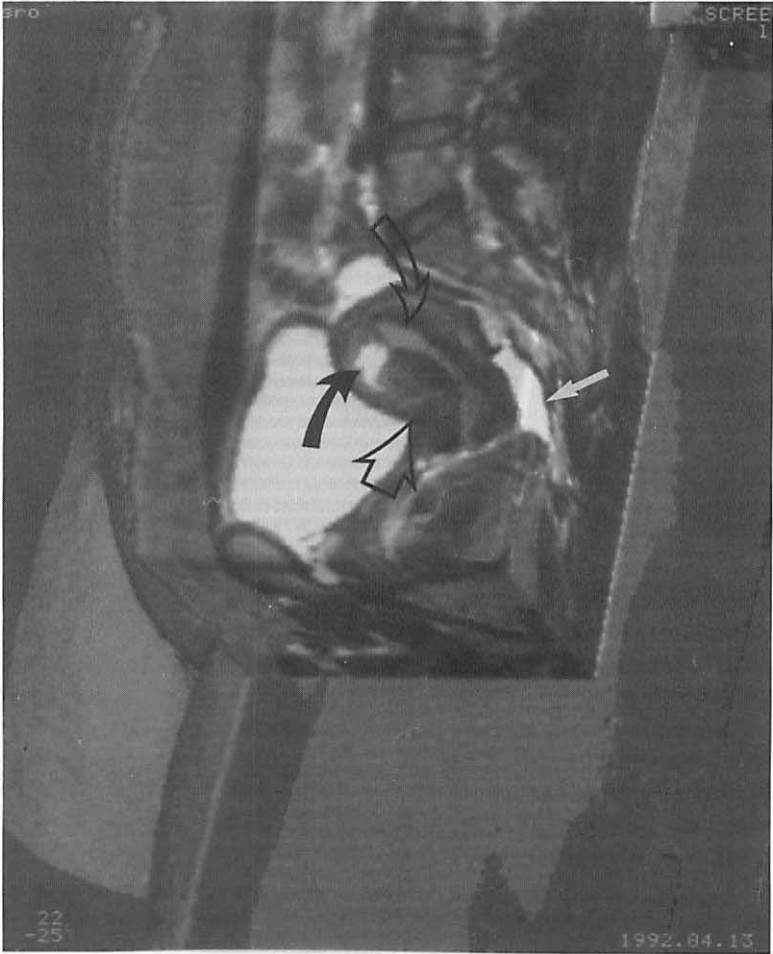


Figure 5b.

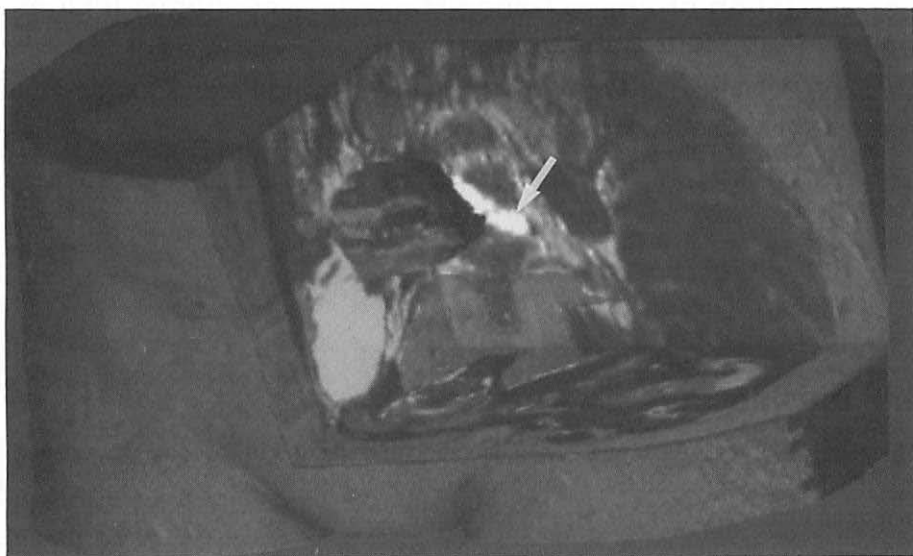


Figure 5c.

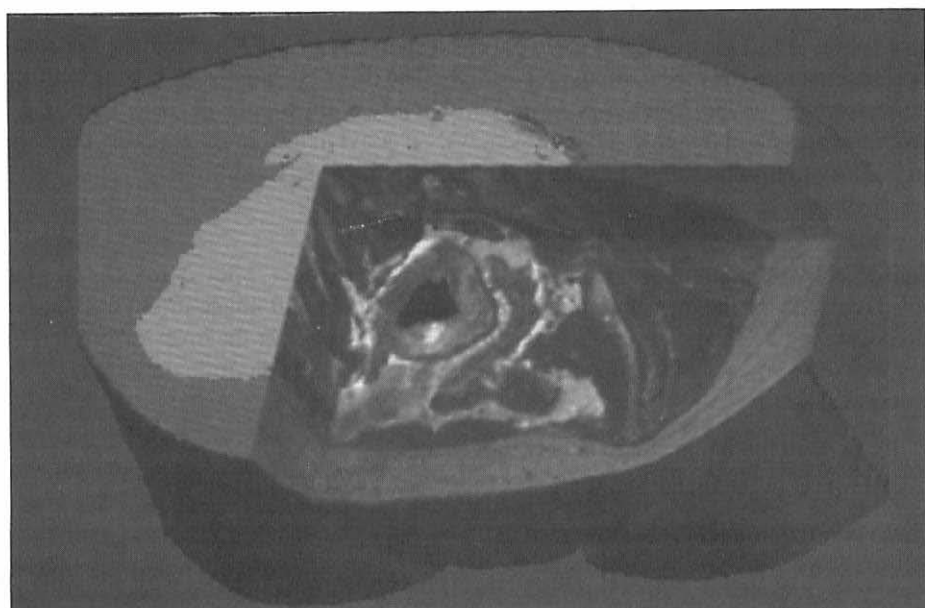


Figure 5d.

Segmentation of Phase-Coded Magnetic Resonance Images Using Mean Field Annealing

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1.0 Introduction

This paper addresses the topics of segmentation and shading in Magnetic Resonance Images (MRI). Segmentation, as defined in terms of this research, involves the association of an image pixel with a label which is representative of some global characteristics which the pixel matches. Segmentation is posed in this research as an optimization problem, solved using a technique known as "mean field annealing (MFA)." This paper also addresses the problem of shading artifacts and proposes a method by which these artifacts can be overcome.

2.0 Segmentation by Mean Field Annealing

Mean field annealing poses segmentation as an optimization problem in which an objective function is defined whose minimum represents a good segmentation[1]. The description in this paper should serve only as a summary of MFA techniques. For further information, the reader should refer to [3]. The theory behind MFA begins with an expression for the maximum *a-posteriori* probability of the unknown correct image f , given the measured image g . The problem is then converted from maximizing this probability to minimizing the associated objective function (Hamiltonian):

$$H(f, g) = H_n(f, g) + H_p(f) \quad (\text{EQ } 1)$$

This objective function is made up of a 'noise' term, H_n , and a 'prior' term, H_p [2]. The noise term relates the measured image to the unknown correct image through a Gaussian noise model. The prior term reflects our prior knowledge of the image characteristics. For the purposes of segmentation, the prior term reflects the following two properties[1]:

1. Regions in the image are locally homogeneous.
2. All pixels in the image should have a value near one of K known values.

These two requirements are expressed as:

$$H_p(f) = H_h(f) + H_s(f) \quad (\text{EQ } 2)$$

Objective functions for $H_h(f)$ have been suggested which result in an image that contains regions of uniform intensity separated by step boundaries[2]. In these objective

functions the expression for $H_s(f)$ has a maximum value when the intensity is equal to one of the K known segmentation values for the image.[1] A prior Hamiltonian satisfying the above properties is:

$$H_s(f) = -b \sum_i \left(\sum_{j \in N_i} \left(\frac{b_{ij}}{2\pi\sqrt{T_p T_s}} \right) \exp \left(- \frac{(f_i - \mu_1)^2 (f_i - \mu_2)^2 (f_i - \mu_3)^2}{2T_s} - \frac{n(f_i - f_j)^2}{2T_p} \right) \right) \quad (\text{EQ 3})$$

N_i is the neighborhood of pixel i . Solving $\min_f H_h(f)$ using MFA will accomplish our segmentation and noise reduction objectives. [2]:

1. Set $T=T_{\text{initial}}$
2. Solve the expression $\min_f H(f)$ using gradient descent.
3. Compare the energy of the new system to the previous energy value. If the new energy is greater, slow the gradient descent using a scalar value λ .
4. If the energy of the system decreases, reduce the temperature T .
5. If $T > T_{\text{final}}$, go to step 2

2.1 Parameter Selection in the MFA algorithm

Equation (3) contains several parameters which exhibit a considerable amount of control over the progress of the MFA algorithm. These parameters affect the convergence rate and can tailor the results to reflect the desired output[1].

b_{ij} represents the bond strength between neighboring pixels. The values for T_p and T_s are the annealing "temperatures" used by the algorithm.[3] They favor the measured values near the beginning of the algorithm, when the temperatures are high, and slowly allow the values to change as the algorithm progresses and the temperatures decrease. Here, temperatures are updated using $T \leftarrow \alpha T$, $\alpha=0(.95)$. Two different temperatures are used to allow the homogeneity term, $H(f)$, to stabilize before attempting to perform the segmentation of the image.

3.0 Characteristics of Magnetic Resonance Images

3.1 Shading in Magnetic Resonance Images

Use of a segmentation objective such as H_s requires that (e.g.) CSF be the same brightness across the image.[1]. For many scanners, however, this assumption is not valid, due to shading. Two images which contain shading artifacts are shown in Figure 1, where it can be seen that these artifacts in an image change the values of many pixels in the image to the point that they are no longer associated with the correct region, resulting in an incorrect segmentation.

3.1.1 Proposed Solution to Shaded Images as Inputs to a Segmentation Algorithm

We postulate a different measure as input to the segmentation algorithm to counteract the effects of shading in MRI. The proton density (PD), T1, and T2 images obtained by

a scanner for a single slice will all exhibit similar shading effects, so the use of a relative measure between two of these images will cancel out the relative change in intensity that occurs across the image.

Given a pair of registered images, each pixel may be described by a vector: (image1value, image2value). The members of a region such as white matter will all be located in a relatively dense area of this space. When shading artifacts are present in the input images, the region in this new space corresponding to a class of matter will be deformed due to the relative changes in the input pixel values. Seen in polar coordinates, this will change the magnitude of the location of the resulting pixel, but not the angle at which the pixel is located. Therefore, we propose the use of the operator:

$$\text{atan} \left(\frac{\text{image1value}}{\text{image2value}} \right) \quad (\text{EQ } 4)$$

to form a new image whose pixels contain the angle at which the pixel is located in the PD-T1, PD-T2, or T1-T2 space.

The angle image between the PD and T2 images was found for a slice that exhibited obvious shading artifacts and is shown in Figure 2. The use of a conventional segmentation algorithm on the two input images would have resulted in incorrect classification in the shaded region, yet we found that the angle image exhibited none of the shading effects present in the input images. In addition, the white matter, grey matter, and csf regions of interest have consistent values throughout the entire angle image.

These results imply that the angles found between the PD, T1, and T2 images are valid measures of the content of the respective slice and do a good job of locating a region for classification. The resulting image satisfies the homogeneity property necessary for 'good' segmentation.

4.0 Method

The images were segmented using the following method:

1. Obtain the phase images for use as the input to the segmentation algorithm.
2. Perform segmentation of the phase images using Mean Field Annealing
3. Assign each pixel to either a white matter, grey matter, csf, or unknown classification.

The input to the segmentation algorithm was an image that contained the angle between either the PD and T1, PD and T2, or T1 and T2 images for a single slice of the brain.

After obtaining the input images, segmentation was performed using the MFA algorithm described above. Each pixel of the output image was then assigned to a white matter, grey matter, csf, or unknown classification based on the output of all three segmented angle images. A segmented pixel from an angle image was classified as a given region if its value was within a reasonable delta value from the mean of that region. This determination was made for each of the three angle images.

These three 'classified' angle images were then used to obtain an overall classified image. If the classification of all three phase images agreed for a given pixel, that pixel was assigned to the appropriate class. If the classification of only two phase images agreed for a given pixel, that pixel was also assigned to the appropriate class, but was designated differently to reflect the diminished confidence in its classification. If the three phase images had different or inconclusive segmentations of the pixel, it could not be explicitly labeled as one of the regions and was assigned a value of zero.

5.0 Experimental Results

5.1 Segmentation of Brain Images

Figures 3,4 and 5 show the input angle images and the corresponding output images from the segmentation algorithm.

These images show that the segmentation algorithm encourages the pixel values to converge to the representative mean values (the μ_i of Eq. 3). For the parameters chosen, however, the algorithm did not classify every pixel as being a member of one of the three classes. Instead, it distinguished between pixels which were valid members of a class and those pixels which did not meet the requirements of being both near a mean and also close to the value of its neighbors.

The image containing the overall pixel assignment is in Figure 6. This figure shows that all three segmented images agreed on the assignment of the white matter in the brain, and it appears to be a solid color as a result. There are two different areas which are segmented as csf. The inner area corresponds to agreement by all three segmented images, while the lighter pixels around the edge of this region correspond to agreement by only two images. It proved more difficult to achieve agreement between the three images in classifying grey matter. The resulting grey matter segmentation in this image is a combination of agreement by either two or three images.

5.2 Mixture Pixels

It was expected that there would be areas between the known regions of the brain which could not be positively identified. These areas correspond to mixtures of white matter, grey matter, and csf and are therefore referred to as mixture pixels. Mixture pixels are generally located on the perimeter of one of the known regions and should therefore take on values in the image that are between the values of the known regions. It was expected, therefore, that the segmentation algorithm would treat these pixels differently than the pixels corresponding to one of the known values.

The behavior of H_i depends strongly on the difference between the value of the current pixel and the value of each of the representative means. For a mixture pixel, the difference is approximately the same between the pixel value and the value of both the representative means which contribute to it. The resulting Hamiltonian will therefore enforce neither of the means and the pixel will not change greatly in value. For a pixel that is affected by noise and happens to fall between two means, however, the noise

portion of the Hamiltonian will force a pixel value to minimize the difference between itself and its neighbors, and will then converge to a proper segmentation.

These effects can be seen in the histograms of output images from the segmentation algorithm. Examination of the histogram of the input T1-T2 angle image shows the presence of several pixels that are midway between the representative means of the white and grey matter (70.5 and 60.0 for this image.) In the output image, several of these pixels have converged to either the white matter or the grey matter. These pixels were most likely valid white or grey matter pixels that were distorted by noise. There are several pixels that remain between the means of the white matter and the grey matter, however. These can most likely be labeled as mixture pixels. They had values in the input image which were between the two means and were also close to the values of their neighbors. As a result, they were not encouraged to move away from either mean and they retained their original values.

From Figure 6, it can be seen that the difficulty in obtaining agreement for the grey matter is most likely due to the presence of mixture pixels between the grey matter and white matter and the grey matter and the csf. These mixture pixels appear black in the image and correspond to inconclusive results from the segmentation images.

6.0 Further Work

These results are preliminary and there are several aspects of this research which suggest possible topics for further research:

1. Investigation of the MFA parameters, including annealing rates, for more insight into the nature of how pixels are segmented (especially mixture pixels).
2. A more sophisticated decision-making process for the regions based on a confidence factor. This confidence factor could be related to the distance from a pixel to the mean of all three regions.
3. More study of the mixture pixels. A more sophisticated decision-making process will probably aid in determining the nature of these pixels.
4. Quantitative comparison of the results of this work with other segmentation algorithms, and with subjective evaluations

7.0 Conclusions

We have shown that by presenting segmentation as an optimization problem, mean field annealing techniques can be used to successfully segment a magnetic resonance image of brain tissue. In addition, this segmentation algorithm also promotes regions of homogeneity in order to reduce the effects of noise before segmentation occurs. The results were very successful in labeling the desired white matter, grey matter, and csf regions.

Additionally, it was found that the use of a relative measure, such as the angle between two images, provides a useful method for avoiding the effects of shading in MRI images.

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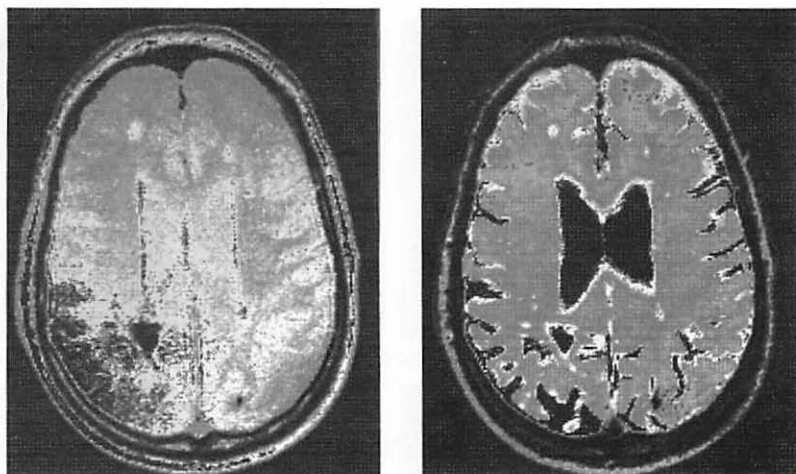


Figure 1. The effects of shading on PD (left) and T2 (right) images.

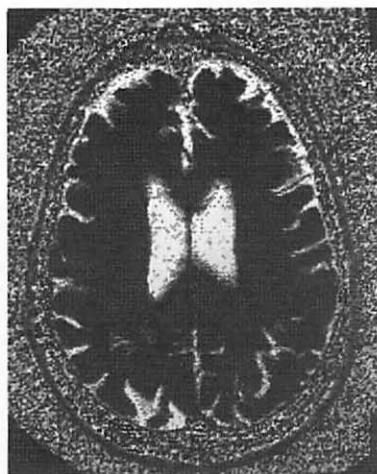


Figure 2. Image of the angle for each pixel in PD, T2 space for the above images.

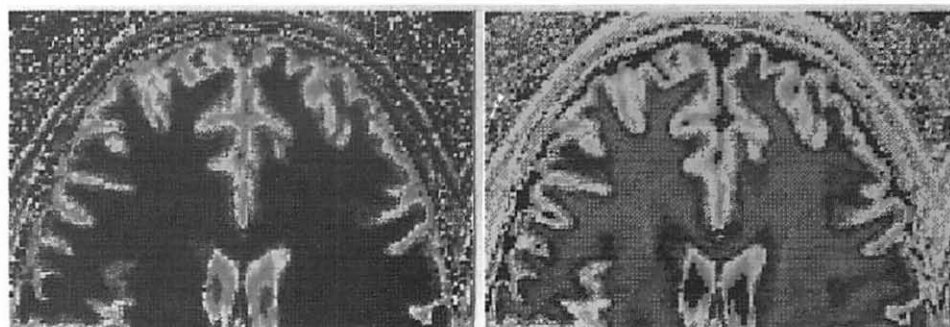


Figure 3. Input T1, T2 angle image and the resulting segmented image.

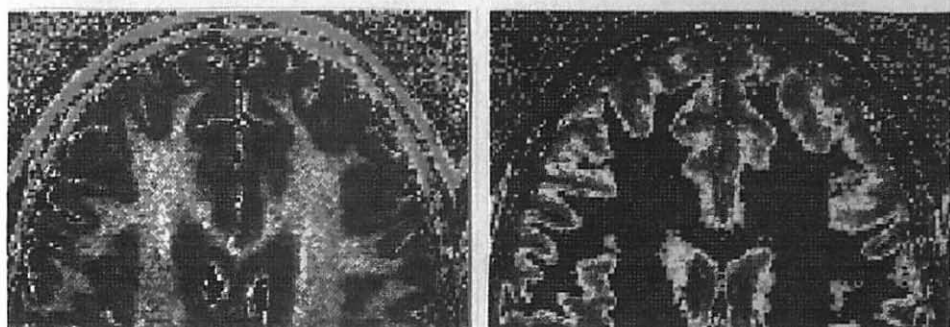


Figure 4. Input PD, T1 angle image and the resulting segmented image.

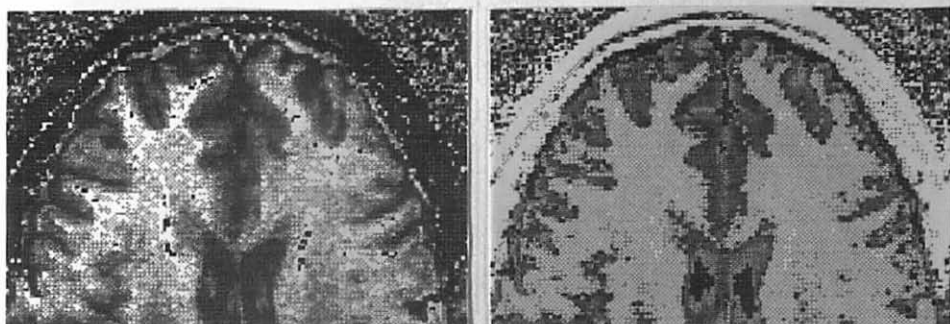


Figure 5. Input PD, T2 angle image and the resulting segmented image.



Figure 6. Final pixel assignment.

The Role of Coronal and Panoramic Reformatted Images in the Design and Placement of Osseo-Integrated Implants

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The development of various alloys capable of undergoing osseous integration is having a significant impact on many areas of medicine and dentistry. Osseo-integrated dental implants are rapidly becoming an accepted form of permanent tooth replacement. It has been estimated that in 1992 over 300,000 dental implants will be placed in the United States alone.² In addition to being key components in endosteal dental implants, alloys capable of undergoing osseointegration are also essential components of hip prostheses. Osseointegration involves the development of a bone to metal contact at the light microscopic level. Successful osseointegration of dental implants is dependent on a number of local biological and mechanical factors. Important biological factors include bone quantity/quality, as well as the relationship of the potential implant site to important structures such as the mandibular alveolar canal, mental foramen and maxillary sinus. Important mechanical factors include the height, width and angulation of the alveolar ridge. This information can not be determined accurately solely by clinical examination. Recent advances in diagnostic imaging now make it possible to accurately determine this information.

The traditional approach to the radiographic evaluation of potential implant sites has consisted primarily of panoramic radiographs. Unfortunately, these images are magnified in a non-uniform fashion; consequently, a true measurement of a given site can not be obtained without taking into account the given magnification factor for a specific site. In addition, the panoramic radiograph does not indicate the buccal-lingual or buccal-palatal width of the alveolar ridge. In many instances this width or thickness is crucial for successful implant placement.

Likewise, one can not determine accurately the quality of bone at a given site or the angle of the vertical axis through the alveolar ridge.

The development of specialized computer software in the late 1980's capable of generating reformatted images of the maxilla and mandible in the panoramic and oblique coronal (cross-sectional) planes has had a significant impact on the pre-operative evaluation of potential implant sites.^{1,4,5} Data needed for generating these images is obtained from thin section axial CT scans. These studies are often performed with the patient wearing a custom made splint with radiopaque markers indicating possible sites of implant placement. Utilizing this software it is possible to accurately determine the relationship of a potential implant site to important structures, such as the maxillary sinus and mandibular canal, as well as determine the width, height and angulation of the alveolar ridge. In addition, it is possible on cross-sectional images to characterize the quality of bone at a potential site and predict whether or not successful osseointegration can occur at this site.³

The development of the original implant software did have a significant impact on implantology; however, it also had several limitations. The software, while providing accurate measurements and bone characterization, does not permit one readily to visualize how well a standard endosteal implant would fit in a potential site. Multiple electronic measurements are often required to determine if the alveolar ridge is suitable for implant placement. In addition, this software does not provide the operator with a true three-dimensional image of a potential site.

Recently, Columbia Scientific Corporation of Columbia, Maryland has developed a system capable of simulating implant placement on axial as well as reformatted panoramic and cross-sectional images (Figs. 1,2,3). This interactive system, known as the IM/Plant-Implant program, has a number of advantages over previous types of implant software programs. One of the major advantages of this interactive system is that it allows the operator to simulate the placement of an implant at a given site and vary its size, position, and angulation. This is done simultaneously on axial (Fig. 1A,B), panoramic (Fig. 2A,B,C)

and cross-sectional (coronal oblique) (Fig. 3) images, thereby affording the operator a three-dimensional perspective. This approach greatly simplifies the evaluation of a potential implant site since it allows one to visualize directly the relationship of the implant's size to that of the alveolar ridge and, if necessary, to modify its dimensions and/or angulation to facilitate successful placement. The technique also enables the operator to visualize directly the relationship of a simulated implant to important structures such as the mandibular canal and maxillary sinus in three dimensions.

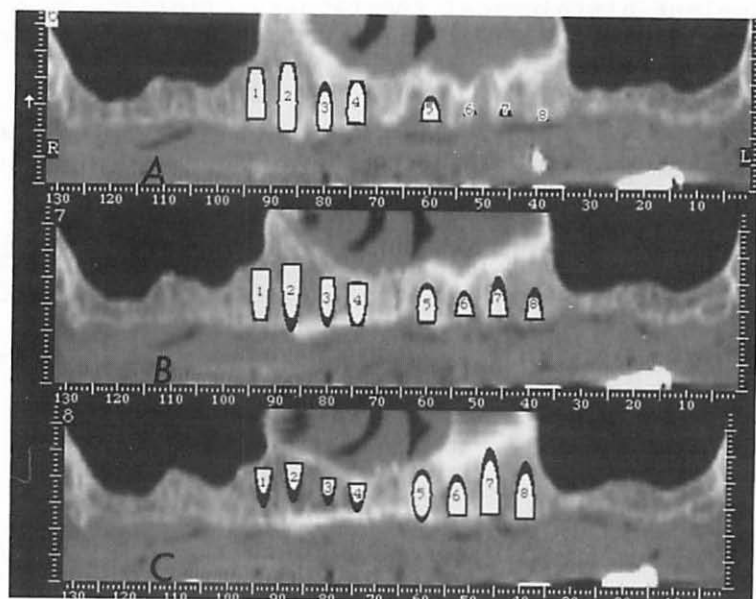
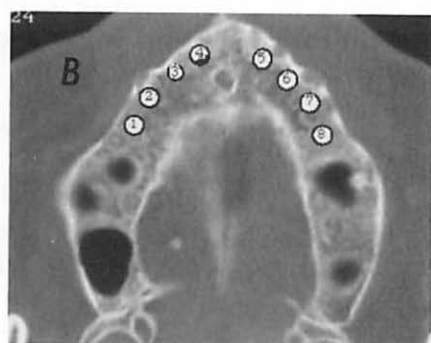
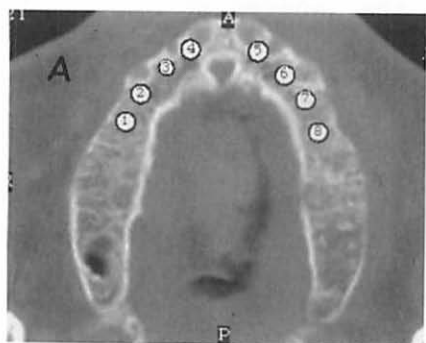
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LEGEND TO FIGURES

Fig. 1A,B. Axial CT sections through the inferior (1A) and superior (1B) maxillary alveolar ridge demonstrating the simulated placement of eight endosseous dental implants. Each implant is indicated by a number.

Fig. 2A,B,C,D. Panoramic images at three different levels in the maxilla demonstrating the relative position of the eight implants in three different panoramic planes (Figs. 2A,B,C). The levels of the panoramic planes are indicated by the three outer black lines on the axial section in Fig. 2D.



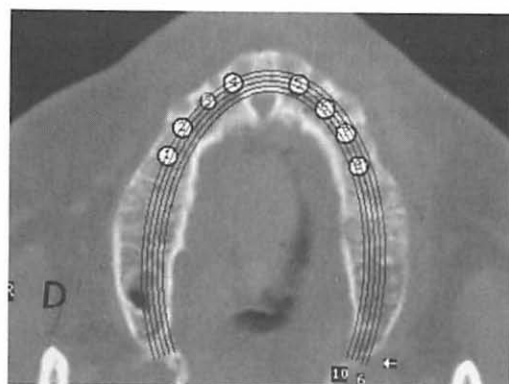
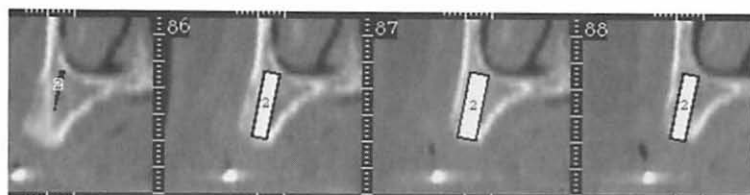


Fig. 3. Series of four cross-sectional images demonstrating the position of implant #2 in the oblique coronal plane. The four sections are consecutive 2 mm thick reformatted images.



SESSION 12

HIS/RIS/PACS/Networking

Chair: Roger A. Bauman

Converting From an Image Database to the ACR/NEMA Transfer Syntax

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ABSTRACT: The ACR/NEMA Digital Imaging and Communications (DICOM) document^[1] proposes some transfer syntaxes for images. However, the use of shadow groups and unclear specifications of the required fields make interoperation difficult as almost combinatoric numbers of protocols can be extracted from the document. One way to cope with this shortcoming, until a standard does emerge, is to use the implemented DICOM format of a hospital's Information Management and Communications System (IMACS) as the reference. This is what was done at the The Bowman Gray School of Medicine of Wake Forest University (BGSM).

Software was developed that maps Picker Magnetic Resonance Imaging studies to our IMACS DICOM format. The software was designed with two goals in mind. First, it could be modified to accept most normal modality images which come with a regular and predictable information header. Second, it could be extended to map from these modalities to a hospital's reference DICOM format.

I. INTRODUCTION

An image from a manufacturer is associated with patient and modality information. The associated information is contained in either a header or in a file containing that information. The image with patient and modality information is an image database entry.

An IMACS must have a database to provide adequate functionality. Until the formation of the ACR/NEMA committee, there was only vague concepts of sharing image databases. However, a milestone was reached in most radiology modalities, except nuclear medicine, when the ACR/NEMA committee agreed upon some fields of a data dictionary. This data dictionary and the loose structure of its transfer syntax form a mechanism for transferring image database entries.

Integrating Picker MRI images with our IMACS was desired at BGSM. It was decided to use the DICOM's data dictionary and much of its transfer syntax. Rather than create a single solution for this modality and then for the other modalities, a

more general approach was used. This approach would provide a mechanism for DICOM translations (harmonizations).

II. INFORMATION REQUIRED.

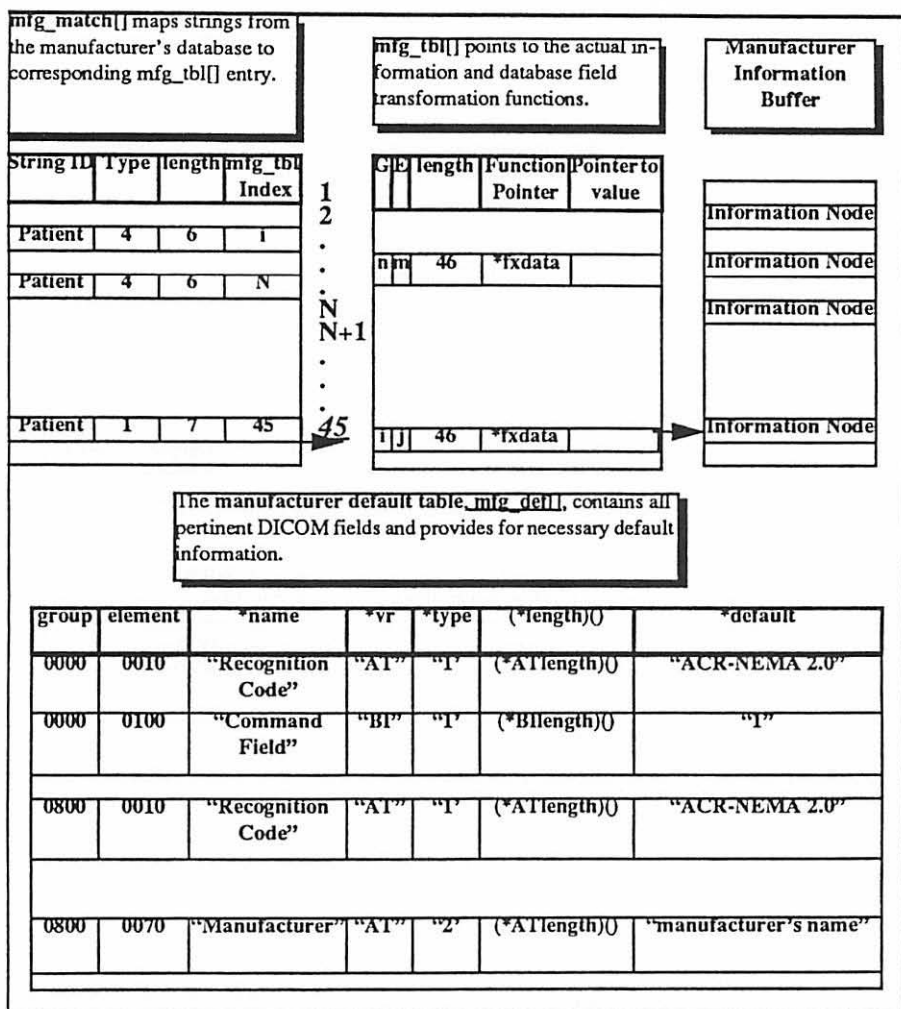
To harmonize an image database entry to the baseline DICOM implementation, five items are required.

1. A pointer to the location of the image
2. A pointer to the location of the information associated with that image
3. A buffer containing default information required by DICOM
4. A mapping from the manufacturer's image database system to the baseline DICOM implementation
5. Subroutines to convert the manufacturer's image database field formats to the formats dictated by the baseline DICOM implementation.

The image pointer is usually easy to obtain. However, access to the other manufacturer-supplied information can be difficult to obtain without special agreements. Given these agreements are made and the baseline DICOM implementation is understood, a program for entering an image into an IMACS database can be written. Since a number of image data base formats are involved, a good approach to harmonize them is to use tables. A key to this table-driven approach is to have pointers to database field translation functions as an entry in one of the tables.

III. IMPORTANT INFORMATION STRUCTURES

The tables of data structures used in this system are shown in Figure 1. The manufacturer default table, **mfg_def[]**, contains DICOM default information which may or may not be contained in the manufacturer's information buffer. The manufacturer's information buffer holds patient and modality information which always supersedes the default information. The manufacturer's table, **mfg_tbl[]**, contains pointers to the actual information and pointers to **field transformation functions**. Finally, the **mfg_match[]** table contains the strings, indexed in a manner that maps the manufacturer's database to corresponding **mfg_tbl[]** entry indexed by the appropriate DICOM group and element.



The field transformation functions are listed below in Table 1.

Table 1 Transformation Functions Required

Function	Purpose
fix_ascii()	Takes an ascii string of a given length which is packed with the space character and deletes the unnecessary space characters, null terminates the string and returns the terminated string in a character array in Ascii Text (AT) DICOM format along with the length.

Table 1 Transformation Functions Required

Function	Purpose
fix_ascii_numeric()	Takes a number represented as an ascii string, null terminates the string returning the terminated string in Ascii Numeric (AN) DICOM format along with the length.
fix_date()	Accepts date as month, day, "19" year which is how technicians type the information into the system and converts to DICOM format (1991.04.21) and passes the length.
fix_float()	If required, converts and returns a manufacturer's floating point to a null-terminated fixed-point AN number with a fixed number of decimal places along with the length.
fix_integer()	Converts an integer to an ascii string and returns the length of that string. This is when an ascii numeric (AN) output is desired.
fix_binary_integer()	Places a long integer into a BI format and returns the length of that string.
fix_orientation()	Obtains and returns the patient orientation during the study acquisition and returns the length of that string.
fix_date_manufacturer()	If necessary, takes date string is started with 19, the manufacturer's date field and converts it to DICOM format and returns that field along with the length of that field.
fix_time_manufacturer()	Converts and returns the manufacturer's time format to DICOM format along with the length of that field.

Figure 1. Conversion Data Structures Used

IV. PROCEDURE

In order to transform the image and the information provided by the manufacturer into the DICOM format used by the hospital, the following steps are taken in the BGSM software.

1. Get a pointer to the image buffer.
2. Place patient demographics and modality information in **manufacturer's information buffer**
3. Initialize data structures and variables.
4. Step through **mfg_match[]** array of structures in order to populate **mfg_tbl[]**.
 - a. parse through the manufacturer's information buffer node to match field names in the STRING ID element, e.g. patient name or image number

b. Find the particular array element of the **mfg_tbl[]**, and pass a pointer to the appropriate data and the length of the data in the manufacturer's information buffer to the **mfg_tbl[]** array.

After this step, the **mfg_tbl[]** has been populated. Its purpose is to provide values to be passed to the DICOM message creation subroutines.

5. Step through manufacturer default table, **mfg_default[]**, (which is a subset of table 10.1 used by the hospital's baseline IMACS DICOM implementation).
 - a. Obtain group and element value, check if it is a long integer which in DICOM is a binary double (BD). BDs are used for group length and length to end values. Call the function **ge()** which stuffs the **group** number, **element** number, writes the length of a long, and stores an appropriate number¹ of zeroes in the value field to hold a place for the correct values. The group length and length to end values are calculated and filled in after the data group has been created.
 - b. Otherwise, check **mfg_tbl[]** to determine if the group and element numbers match. If the group and element pair is there, use the information to which it points. Call the function **(*fx_data)()** to convert the data in the manufacturer's information buffer and obtain the length. Call **gelv()** which passes the group and element number, length of the field, and the value to the target DICOM buffer.
 - c. If no match is found, use the default value in the **mfg_default[]** array. The length is obtained from **(*length)()** in the **mfg_default[]**. Call **gelv()** which passes the group and element number, length of the field, and the value to the target DICOM buffer.
6. As each group is completed, calculate current group length and place that information in the previously reserved location.

This creates the DICOM message. Testing must follow in order to verify the translation is correct. Once completed, the only two decisions remaining are to determine how the images and manufacturer-supplied information are sent to the translation machine, and where the translation machine is located.

V. CONCLUSIONS

This methodology can integrate Picker MR images into our IMACS. This procedure is now being modified to integrate PET images. Companies like PBT Technologies provide a mechanism for extracting images from medical systems with nine-track tapes and mounting them on a workstation using the Network File System (NFS). The software methodology used in this project could be used with

1. A long integer value (32 bits)

the PBT product to provide an elegant integration of images from older imaging equipment with an IMACS provided manufacturers are willing to share data formats with a software developers using this procedure.

VI. REFERENCES

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Integrated Computer Systems for Radiology Department Management

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OVERVIEW OF THE HOSPITAL INFORMATION SYSTEM

The Hospital Information System (HIS) implemented at the Medical University of South Carolina (MUSC) allows each department to choose the most appropriate Departmental Information System. Because the HIS is designed to integrate dissimilar products, each department can evaluate prospective systems with minimal restrictions regarding the vendor, hardware platform, or operating system. This allows more careful consideration of the product functionality, the service history of prospective hardware and operating system vendor(s), and the support record of the information system vendor.

The Health Level 7 (HL7) message passing protocol has been adopted by MUSC as the best existing standard for inter-systems information exchange. Existing systems utilize HL7 interfaces to pass Admission, Discharge, and Transfer (ADT) information; results such as drug profiles and radiology reports; and billing/charge information. All new systems, and replacements of existing systems (or interfaces), are required to employ the current HL7 standard specification; ie., to meet the requirements of a department's request for purchase, the vendor must provide a full HL7 interface.

Currently, most vendors have implemented their interfaces over RS-232 serial connections. At MUSC, we have such interfaces in place for Radiology, Pharmacy, Laboratory, Patient Registration (ADT), Physical Therapy, Occupational Therapy, and Respiratory Therapy. To support upcoming projects, MUSC is also requesting that vendors implement the required HL7 interfaces using TCP/IP network protocol standards. In those cases where vendors are unable to meet this request, serial connections are still accepted.

Bell-Atlantic Healthcare Systems' (BAHS) StatLAN product provides the mechanism which ties our multivendor HIS together. Utilizing a PC-based local area network, StatLAN distributes and links information from a variety of independent and decentralized ancillary systems. StatLAN reliably manages distribution of basic patient registration information to each of the ancillary information systems. This

synchronization ensures that each ancillary has consistent data for vital demographic information such as Medical Record Number, Visit Number, Insurance Provider, etc.

StatLAN workstations display pertinent hospital information on nursing units, in clinicians' conference rooms, and other strategic locations throughout the hospital. The 250 StatLAN workstations provide a single point of access to critical data from pharmacy, radiology, and the laboratory. The workstations are also used to track patient location, allergies, and other valuable information. In the near future, nurses and doctors will be able to place ancillary orders from the workstations as well.

The local area network at MUSC uses Ethernet implemented over twisted-pair wiring. Fiber-optic cable connects concentrators in phone closets throughout the hospital and surrounding buildings. Network bridges are used to isolate individual department traffic from the hospital backbone. Future plans include network routers to further isolate departmental traffic where necessary; ie. Radiology's newly installed Picture Archival and Communications System (PACS).

OVERVIEW OF THE RADIOLOGY INFORMATION SYSTEM

The DECrad Radiology Information System is designed to improve coordination among the radiology department's staff, resources, and patients. DECrad is used to record and maintain patient and exam data including patient demographics, exam scheduling, patient tracking, film management, diagnostic reporting, resource utilization, and accounting services.

Patient arrival in the Radiology department is normally hassle-free because the patient demographics are electronically transmitted from the Patient Registration system via StatLAN. Upon arrival in Radiology, the patient is asked only to verify the information and answer a few supplemental questions. The StatLAN interface ensures the integrity of the medical record number, Visit Number, and patient demographics.

Once a dictated report has been transcribed, it is available hospital-wide via StatLAN. Physicians interested in a radiology report can view the text on any StatLAN workstation. Currently, both preliminary and finalized reports are available. MUSC plans to store five years of reports online in the DECrad system; however, the system has only been operational for 3 years.

The DECrad system consists of a DEC VAXcluster with two 6310 CPUs and supporting fixed disk devices. The fixed disk system is shadowed for data integrity in case of a disk crash. The system is accessed by approximately 80 dedicated DEC VT terminals, 84 barcode readers, and 20 printers located throughout the Radiology department.

The radiology department also uses a Novell network for office automation programs such as electronic mail, word processing, graphics, databases, and spreadsheets. To maximize the use of available resources, physicians and other radiology personnel may also access DECrad from their desktop personal computers over the local area network. Terminal emulation software, with the proper keyboard mapping, allows physicians to electronically sign radiology reports from their desks. Remote modem access to DECrad allows physicians to sign and query reports from home. Support staff download DECrad management reports into PC spreadsheet software for more detailed analysis. Quality assurance information is downloaded into database software. Seamlessly integrating the Novell network with the DECrad RIS is a departmental goal.

CONNECTION OF THE DECrad SYSTEM TO THE HIS

The StatLAN Network Interface Unit (SLNIU) from Bell-Atlantic Healthcare Systems connects the DECrad system to the Hospital Information System. The SLNIU consists of an IBM ps/2 Model 55SX with an Ethernet connection and a MicroChannel serial board with 8 serial ports.

The SLNIU software acts as a translator converting from the StatLAN message protocol to the HL7 message protocol. The SLNIU supports bidirectional message passing as required by the HL7 specification. This allows real-time updating of patient registration information. Additionally, on-demand report querying from the StatLAN workstations is supported.

The Ethernet interface connects the SLNIU to the StatLAN (Hospital) network while the serial ports provide multiple connections to the DECrad VAX computer. Presently, three serial ports are in use. One serial port is used to pass ADT information from StatLAN to DECrad. The other two ports are used to pass Results (transcribed reports) from DECrad to the StatLAN workstations. Two Results lines allow multiple result requests since a transcribed report can take several seconds to be transferred. Future plans include Orders and Billing connections. Additional results lines will be added as demand requires.

THE RIS AND ADT INFORMATION

Whenever a relevant event occurs in the hospital's Professional Healthcare Systems (PHS) patient registration system, a message is sent to StatLAN. Relevant events include admissions, discharges, transfers, and updates. StatLAN guarantees delivery of all ADT messages ensuring the data integrity among all the ancillary systems. The mechanics of the ADT message transfer to DECrad are as follows:

- 1) PHS uses an RS-232 connection to send the ADT message to StatLAN.

- 2) StatLAN attaches a sequence number to the ADT message.
- 3) StatLAN sends the sequenced ADT message to the SLNIU and other ancillary systems via Ethernet.
- 4) The SLNIU translates the StatLAN message protocol into HL7 protocol.
- 5) The SLNIU sends the HL7 message out the ADT serial line into a DECServer 200 terminal server. The DECrad system has a process running which recognizes input on the designated DECServer port as incoming ADT messages. This process is called the **ADT Link**.
- 6) Once the message has been received, the ADT Link process sends an acknowledgement to the SLNIU.
- 7) The SLNIU sends an acknowledgement to StatLAN which signals the receipt of the sequenced ADT message. This acknowledgement only means that the ADT message was correctly received. It does not represent an acknowledgement of the correctness of the information. That function is left to the DECrad System.

If an ADT message is not acknowledged by the DECrad System, StatLAN will not send any more ADT messages until the problem is corrected. StatLAN will continue to attempt to send the same sequence number ADT message until it is acknowledged. When the problematic message is finally acknowledged, StatLAN will continue sending the ADT messages that have queued up since the problem began.

THE RIS AND TRANSCRIBED REPORTS

The SLNIU also acts as the gateway between the StatLAN workstations and the Radiology reports database. From any of the StatLAN workstations, a user can access Radiology reports. Once a user has selected a patient, they can ask to see available radiology reports in reverse chronological order or by list of radiologic procedures performed. The mechanics of the results message transfer from DECrad are as follows:

- 1) The StatLAN workstation sends a StatLAN protocol request message for available radiology reports to the SLNIU. The reports can be listed in reverse chronological order or by radiologic procedure performed.
- 2) The SLNIU translates the StatLAN request message and sends an HL7 request message to DECrad to query the available reports for the specific patient.
- 3) DECrad responds to the SLNIU with an HL7 message which lists the available reports.
- 4) The SLNIU translates the HL7 message and sends the list of available reports back to the StatLAN workstation in StatLAN message protocol.
- 5) Once the user makes a selection at the workstation, a procedure specific request is sent to the SLNIU.

- 6) The SLNIU again translates the StatLAN protocol request message and sends an HL7 request message to DECrad to query the specific report requested.
- 7) DECrad responds to the SLNIU with a series of HL7 messages which contain the requested report.
- 8) The SLNIU sends the report back to the requesting workstation in a series of StatLAN protocol messages.

It is important to note that the results query lacks the strict guaranteed delivery rules that are followed for ADT messages. Although report delivery to the StatLAN workstation is not guaranteed, it is checked for errors as it is transmitted. If the integrity of the message is in question, the user at the workstation is notified that they should request the report again.

Radiology reports are currently made available to StatLAN users as soon as they are transcribed. These reports are clearly marked as PRELIMINARY. Once the report has been signed off by the responsible radiologist, the report status is changed to FINALIZED.

THE RIS AS SYSTEM INTEGRATOR

Once the information has been passed from the HIS to the RIS, DECrad then assumes the role of integrator for the other systems within Radiology. Currently, the Radiology department has a digital dictation system, a Philips PACS system, and a Philips Computed Radiography (CR) system. In the near future, the department plans to add an AGFA PACS system for Ultrasound. Each of these systems will interact with the DECrad system to get patient demographic information, scheduling information, exam status information, and transcribed reports.

HOW THE RIS AND DIGITAL DICTATION SYSTEMS INTERACT

The Radiology department at MUSC uses Dictaphone's Digital Express 7000 digital dictation system. The dictation system enhances the Radiology department's ability to meet the demands of the hospital staff for timely delivery of radiology reports. Because both systems contain information needed by the other, an electronic interface was established. It is important to note that the interface is between the RIS and the dictation system--not between the dictation system and the HIS. It is also important to note that the DECrad-to-Digital Express interface is implemented using the DECrad proprietary messaging system and an RS-232 serial connection. Since the interface is to DECrad and not the HIS, the HL7 message protocol is not mandatory.

Because DECrad has the patient demographic and exam-related information,

it acts as the master information server. DECrad sends the patient name, medical record number, and exam number to the dictation system. The dictation system is responsible for updating relevant exam information in DECrad such as exam status and dictating radiologist.

Once an exam is dictated by a radiologist, the exam is ready to be transcribed. The dictated reports are routed to the transcriptionists on a first-in, first-out basis. Additionally, the dictation system is responsible for several updates to the DECrad databases.

The dictation system, having been told that the dictation is completed, sends a message to DECrad to change the exam status from "Exam Completed" to "Exam Dictated." The dictation system also updates the "Radiologist" field in DECrad with the dictating radiologist's name.

When several exam numbers are dictated as a single report, the dictation system sends a message to DECrad to "associate" all the exam numbers under a single exam number. This allows the DECrad report to be pulled up by any of the associated exam numbers.

Because the exam status change is done in real-time by the electronic interface, management reports can be produced which accurately reflect how much time elapses between the end of the exam, the end of the dictation, and the end of the transcription. Furthermore, since the patient name and medical record number are received from DECrad, there are fewer problems maintaining data integrity.

HOW THE RIS WILL INTERACT WITH THE PHILIPS PACS

Although not currently implemented, the interface between DECrad and the Philips PACS is being developed as an HL7 interface implemented over an RS-232 serial connection. The interface will send patient demographics from DECrad to the PACS. The electronic interface will ensure that the correct patient name, sex, birth date, and medical record number are stored with the patient's PACS images.

HOW THE RIS WILL INTERACT WITH THE PHILIPS CR SYSTEM

The DECrad-to-Philips Computed Radiography (CR) interface is still in the planning phases; however, a general outline has been developed. It will be an HL7 interface implemented over an RS-232 serial connection. The interface will send patient demographics and scheduling information to the CR system as well as update exam status information in DECrad. The interface will be designed to reduce double-entry of patient name, sex, birth date, and medical record number. Additionally, the scheduled exam date and time should be transmitted from DECrad to the CR system.

When the patient arrives, DECrad will send an exam number to the CR system. When the patient's images have been processed, the CR system will change the DECrad exam status from "Exam in-progress" to "Exam completed."

SUMMARY

The integrated radiology system has provided a number of advantages to the department. Some of these are readily measured while others are subjective. Among the measurable improvements are a reduction in unreported films, a decrease in the average turnaround time for a report, a reduction in the number of film retakes, and an improvement in collections.

Subjective improvements include fewer complaints from referring physicians, better communication among staff members in radiology, better access to old films and reports (more accurate and timely response), better utilization of equipment, and better access to patient records for research and teaching. Because the system reduces waiting times, the patients receive better service from radiology.

By integrating the RIS with the patient registration system (via StatLAN), the information in DECrad is more accurate and reliable. The electronic updating of patient demographics not only ensures its accuracy, but it saves time and resources since personnel are not required to collect and enter the information. It also provides data consistency among the ancillary information systems.

Using StatLAN, the radiology reports are available throughout the hospital quickly and easily. The ease of access builds confidence among hospital staff and adds value to radiology's role in the patient care process. This perceived value is increasingly important in today's healthcare environment.

The radiology information system at MUSC serves two important roles. First, it is used as a management tool to guide the decision-making process within radiology. To support this role, the RIS is used for patient tracking, exam scheduling, film management, resource allocation, and other departmental information tracking. The second role of the RIS is that of integration manager. The RIS has become a communications hub that manages the flow of data to and from the hospital information system. Additionally, the RIS acts as a data distributor for several subsystems within the radiology department. Having received its information from the HIS, the RIS then redistributes that information to connected subsystems.

Integrating Image Management With a Radiology Information System

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ABSTRACT

Brigham and Women's Hospital is implementing a multi-modality picture archiving and communications system, first within the Radiology department, and eventually throughout the hospital campus. The system is initially focused on the digital modalities CT, MR, NM, and US. The principal clinical uses of the system are consultation-review and treatment planning; the emphasis on film-based primary interpretation will be maintained for all modalities. Image management has been integrated with the existing Radiology Information System, DECrad. The DECrad database was extended to include several new image-related data elements. Prototype software modules controlling image migration have been developed. The modules communicate with DECrad through an Application Programming Interface (API) developed for this project. API functions consist of patient demographic queries and image status queries and updates. Image data files are stored externally to DECrad in a network file-server. Network communication with the database is achieved through a task-to-task DECnet link connecting acquisition and display nodes with the DECrad system. Results of this implementation to date have been very positive. No major interoperability or connectivity problems have surfaced. Work is on-going to complete the prototype software modules and expand the functionality of the DECrad API. Conversion of the API to a DICOM messaging scheme is planned.

INTRODUCTION

A fully functioning and reliable digital picture archiving and communications system (PACS) is desirable to have within a hospital campus for both clinical and research use. The many benefits of storing and retrieving images electronically are becoming more obvious as the ratio of digitally-acquired images to film-based images grows. The demand for timely access to digital images is increasing within radiology and expanding to departments outside of radiology. Brigham and Women's Hospital (BWH) Department of Radiology currently is providing support and access to digital images for the following clinical and research uses;

- 3D MR angiographic reconstructions
- Radiation therapy treatment planning
- Stereotactic biopsy and radiosurgery
- Quantitative computed tomography (QCT)

- Cranial-facial surgical planning
- Neurosurgical and abdominal surgical planning
- MR-SPECT data fusion
- Multiplanar image reconstruction
- Electronic teaching files of interesting cases
- General research use

The procedures now in place to service these activities are inadequate to support any further growth. In addition, new display applications are desired for remote consultation and review of images by referring physicians, and there is some interest in experimenting with soft-copy primary interpretation. These factors have influenced the decision to implement a digital PACS system at BWH.

PACS MODELS FOR DATABASE MANAGEMENT

Most PACS implementation schemes conform to a similar functional model which embodies certain essential features, such as acquisition, archival, display, and database management. Much of the work in building a PACS involves development of software modules to perform these functions. To control image management effectively, these modules require on-line access to up-to-date patient and scheduling information. Institutions contemplating installing a PACS will likely already have an existing patient information system that contains this information, either in the radiology department (RIS) or hospital-wide (HIS). How to coordinate the patient database (PDB) and the image database (IDB) is a key decision in PACS design. There are two main approaches to accomplishing this; as an interface, or as an integration.

In the interface approach, the IDB and PDB are maintained as stand-alone systems with a communication-translator link connecting them. Using this interface, patient demographic and exam information is exported from the PDB as it is acquired, and duplicated in the IDB [1,2]. Image acquisition, file migration directives, and user queries to view images, are all directed to the IDB. Examination scheduling and other non-image related user queries continue to go to the PDB. This model maintains a clear line of demarcation separating PACS functions from other hospital functions. As a consequence, the IDB can be more easily ported to another environment with a different PDB by writing a new communication link. A disadvantage is that extreme care must be taken to insure that the two databases are kept synchronous, which can be problematic.

In the integration approach, image management is incorporated as an extension to an existing PDB [3]. This model treats image archiving and retrieval as a natural evolutionary enhancement to a successfully functioning database management system. The extensions necessary to the PDB to support imaging are moderate, mainly some additional data fields for an acquisition state table and storage of the location of the image data-sets (pointers). The image data-sets themselves are stored externally to the PDB in a network-accessible hierarchical file-server archive. Also needed is an Applications Programming Interface (API) to the PDB, adapted for network communication. The advantage of an integration is that all queries are directed to one

database, which is already in place and fully supported. The massive effort to first recreate all data items, validate them, and then maintain them in perpetuity is obviated. An integrated system will be more robust, easier to implement and maintain, and leverages valuable existing resources. Portability of the system can be realized if the API to the PDB is designed to conform with ACR/NEMA standards for messaging [4]. The integration approach pre-supposes that the engineering expertise, access to development tools, and contract rights to modify the PDB software system exist or are readily available.

BWH PACS MODEL

A functional model has been developed at BWH which embraces the integration approach using DECrad (Digital Equipment Corp., Maynard, MA) as both the IDB and PDB; DECrad is an M [5] based RIS. Our model incorporates all the essential features of a PACS system; acquisition-validation, pre-processing, archival, pre-staging, retrieval, display, and exceptions handling [6]. Work flow is event-driven; acquisition servers monitor the MR and CT scanners and capture images as soon as they are reconstructed. Acquisition servers identify images by comparing image header information with information stored in the RIS. Image studies are pre-processed (window/level, lossy and lossless compression) to facilitate storage, retrieval, and progressive transmission of data to display stations. Image data-sets migrate over time to and from a permanent archive, consisting of a hierarchy of on-line, near-line and off-line storage. Historical examinations are retrieved from the archive during off-hours and pre-staged to the appropriate display stations for viewing along with the current exam. Exceptions are reported and processed interactively by the radiological technician.

IMPLEMENTATION OF BWH MODEL

There are several different approaches to building a PACS ranging from totally in-house developed to turn-key systems [7], with advantages and disadvantages to each method. Since there is no existing system available for purchase which fulfills all of our functional requirements, a custom development is necessary. The feasibility of contracting with outside systems integrators is being investigated. In the meantime, in-house development is proceeding; the objective is to prove the concept of database integration and to gain experience and first-hand knowledge by developing a functional prototype system.

Brigham and Women's Hospital is an excellent test environment for such a system. The Department of Radiology has been using DECrad as the RIS for seven years, and is supported by a small but knowledgeable and experienced staff. The DECrad host computer is a VAX/VMS/DSM system which is a central node on the radiology network (ethernet). The digital imaging modalities within the department (CT, MR, US, NM) are also connected to this ethernet (or will be very soon), as are various image display workstations (DECstations, Suns, Macintoshes) and file-servers. Development is following a rapid prototyping strategy; the working premise is the understanding that a complex system that works evolves from a simpler system

that works. Prototype software modules have been developed (in C) to perform many of the PACS functions mentioned above. The software has been deployed onto servers where appropriate. Modifications were made (in M) to DECrad to allow these distributed modules to query the database via an API. The API uses a task-to-task communication interface provided by DECnet to accomplish the network link. Acquisition is focused on the digital modalities CT, MR, NM, and US. Display stations are being deployed first within the radiology department. Since the budget is limited, existing resources are being used wherever possible and large investments in new hardware (e.g. optical disk jukebox) are being deferred.

The API to DECrad is a key component of the system. The API consists of a library of query and update modules, written in C, designed to be called mainly from the acquisition, display, and image-migration service modules. At the heart of these calls is the communication link with the DECrad database. This link is a task-to-task network communication protocol supported by DECnet Phase IV (Digital Equipment Corp., Maynard, MA), similar in functionality to the remote procedure call (RPC) available under TCP/IP. An I/O channel to DECrad can be opened by any authorized DECnet node on the network and a synchronous data transfer session established. Multi-vendor connectivity is supported; in fact, most of the DECnet nodes in use at BWH are Sparcstations using DNIlLink software (Sun Microsystems, Mountain View, CA). DNIlLink is a DECnet emulation package; early minor interoperability problems have been corrected in DNIlLink version 7.

API calls to DECrad are keyed either on the patient medical record number, or on the accession number. DECrad automatically issues a unique accession number to each radiological examination. The accession number is used to create unique identifiers for all data-sets generated by the acquisition servers. These identifiers, along with image status information, and other metadata are stored and retrieved in DECrad using the API. The calls currently supported are listed in Table 1.

RESULTS AND FUTURE WORK

Results to date have been very positive. CT and MR data are routinely being acquired with minimal adverse impact on the acquisition devices and the ethernet network. There has been no noticeable degradation of DECrad response time for interactive users. However, there are currently very few image-related transactions going on other than for acquisition and testing. The DECrad VAX will be upgraded as necessary to handle the expected increased load before the system is rolled out. The local area network is fiber-optic throughout the campus with connections to several neighboring hospitals. Twelve strands of multi-mode fiber have been terminated in 93 phone closets throughout the campus, of which four strands are reserved for clinical imaging. Work is underway to re-engineer the network locally for PACS, including isolating acquisition and inquiry subnets, and upgrading from ethernet to FDDI.

Software development is on-going to complete the proof-of-concept prototypes and to expand the API to facilitate pre-staging of images based on DECrad scheduling information. Other planned improvements involve moving from vendor-proprietary

formats to DICOM standards. These improvements include replacing the DECrad accession number used for labeling datasets with the DICOM identifier (DSID), converting image file formats to the DICOM standard, and replacing our non-standard API with a DICOM messaging scheme.

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Table 1. Calls currently supported by the DECrad API

a) Demographic Query

Passed: Medical record number.

Returned: Patient name, DOB, age, sex, date of last admission, and film location (if any).

b) Exam listing Query

Passed: Medical record number.

Returned: Reverse chronological listing of exams in the clinical system database.

c) Diagnostic Report Query

Passed: Accession number.

Returned: Report text and status (preliminary or final) stored under that examination.

d) Image Status Query

Passed: Accession number.

Returned: Data elements for image type, image creation date, author node, archive location, image publish date, image frame count, image data-set filenames (retrieval path), as well as a series of image-related flags in the Acquisition State Table.

e) Image Status Update

Passed: All or some elements listed under Image Status Query.

Returned: Confirmation

Integration of Images with Radiology and Hospital Data in an IMAC System

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The Integrated Diagnostic System (IDS) is a developmental image management and communication (IMAC) system currently implemented at the Medical College of Wisconsin. The system links several CT and MRI systems, independent imaging consoles and workstations for radiologists and referring physicians. Information about patients, such as demographic data and radiology reports, originates from the radiology information system (RIS) and hospital information system (HIS). Image data are generated and transmitted by the imaging devices and workstations. The system's archive manager integrates these disparate data and can transmit images and text together to physicians' viewing stations.

The current IDS system integrates widely separated pieces of equipment; currently, two CT scanners at Froedtert Memorial Lutheran Hospital and two MRI systems at Milwaukee County Medical Complex serve as the image-acquisition devices for the network. Because these two hospitals have different information systems, we decided to integrate IDS with only one hospital's information system in the initial implementation. We have developed interfaces between IDS and Froedtert Hospital's RIS (IBAX Patient Care System) and HIS (SMS Action).

To limit the volume of imaging procedures to be included in testing image-text integration, we selected two outpatient clinics at Froedtert Hospital as test sites. We chose the neurology and gastroenterology clinics, which frequently request CT and MRI studies of their patients. Image-review stations were installed into these clinics and the clinic physicians and staff were trained in the use of the system.

When a referring physician requests an imaging procedure, the RIS captures the necessary patient demographic data from the HIS. After the procedure is completed, the RIS prompts the radiology technologist or coordinator to confirm the patient's medical-record number and the procedure code. The system also asks that person to enter the date and time that the procedure was completed, the imaging device identifier (e.g., "CT/1") and the study number (which is usually an accession number for studies on each imaging device). Once the radiology report is dictated, transcribed and verified, the RIS transmits the demographic data and report to the IDS archive. The imaging device transmits the images directly to the archive.

The archive manager, an IBM AS/400 system that serves as the central control unit of the system, integrates these data with the set of images by matching the study's identifying data captured by the RIS. The storage manager, which acts as a server to the archive manager, provides 1.2 GB of hard-disk intermediate storage and an interface to the 20-GB "jukebox" of magneto-optical disks. Reports and images can be transmitted in American College of Radiology - National Electronics Manufacturers Association (ACR-NEMA) format from the archive to the radiology and referring-physician workstations.

To allow communication among the various computer systems, several special interfaces were developed. The interface between the RIS and the HIS was implemented as part of the RIS installation. The RIS-IDS interface allows the IDS archive manager to receive patient demographic and report data from the RIS. Customized software was developed for the IBAX RIS to format and transmit reports to the archive manager as soon as they are marked as "verified" within the RIS. Because no standard has been accepted, we adopted the early proposals for HIS-RIS-PACS communications protocols from the ACR-NEMA Working Group VIII. Patient-identification data and radiology reports are transmitted in a logical ACR-NEMA data stream, with the data elements embedded into "shadow" groups.

Once the archive manager has received the radiology report and set of images of a patient's imaging study, it must match them so that they can be stored and retrieved together. The patient's medical record number and radiology requisition number are generated by the RIS, and are entered into the imaging device by a radiology technologist. The device ID and study number are generated by the imaging device, and are entered into the RIS after the study has been completed. The archive manager contains a routine that uses these and other pieces of information to match reports with images. A manual matching routine is available to match studies with discrepant data, for example, where a patient ID number was entered incorrectly into the imaging device.

The archive manager must be able to update the report associated with a specific imaging study. If a report is modified or an addendum is written, the RIS transmits the new report to the IDS archive manager. The more recent report is added to the archive with a timestamp to indicate when it was received. The original report is not deleted. When a user views the imaging study, all reports are transmitted from the archive to the workstation, where they are displayed in reverse chronological order.

The implementation of the IDS system has changed the way the technologists, transcribers and department coordinators manage image and report data. These changes in the reporting process initially resulted in inconsistent entry of patient and study ID codes. These mistakes reduced the availability of image and report data and diminished the effectiveness of the system. Although the occasional mis-entry of patient identification data led to unmatched images and reports, the data were correctly easily. As the radiology personnel became more familiar with the new system, these problems abated. The automation of several manual procedures, such as entry of

patient ID data into the imaging devices, may obviate such problems in the future. We are exploring the development of an interface between the RIS to the individual imaging devices to help overcome this potential problem.

The system's users reacted favorably to integration of images and report text at a single, familiar workstation. They found it much easier to use the IDS system than to turn to several different workstations or terminals, each with its own user interface.

Open Systems as an Information Distribution Strategy in an Academic Medical Center

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INTRODUCTION

Many academic medical centers developed information systems plans in the late 1970's and early 1980's which used large mainframe computers and proprietary software as the hub for both clinical and administrative computing activities. With changes in technology and greater emphasis on departmental-specific applications (such as digital image storage and retrieval), the integration of applications becomes technically more difficult and increasingly costly under this approach. The University of Maryland Medical System reevaluated its mainframe-based information systems plan and developed an Information Distribution Strategy to lay a foundation for rapid changes in technology, new initiatives in departmental computing, and to control spiraling costs in information systems.

BACKGROUND

The University of Maryland Medical System (UMMS), a 747-bed academic medical center located in downtown Baltimore, was created in 1984 as a private not-for-profit corporation. In 1985, the UMMS developed a five-year Strategic Information Systems Plan to address deficiencies in clinical and administrative computing capabilities. Using an outside consulting firm, the planning process involved key representatives from the School of Medicine, clinical administration, nursing, and ancillary departments.

The 1985 UMMS Strategic Information Systems Plan was similar to many information systems plans developed for larger hospitals during the late 1970's and early 1980's. The plan called for a central IBM mainframe computer as the heart of the communications strategy. It recommended selecting a single vendor for both clinical and financial applications so that a unified clinical and financial database could be created. Ancillary systems such as lab and radiology, if not available from the primary software vendor, would be interfaced directly

to the mainframe systems. From an organizational perspective, the plan required a large centralized information systems department. The first systems to be implemented would be the patient billing and admitting system, followed shortly by the installation of the order communications system. All systems were to be implemented by 1990.

By July, 1989, only the first system in the long range plan had been implemented. The patient billing and admitting system significantly overran its budget and it took two years longer to implement than originally planned. At the same time, environmental changes on the University campus caused the entire strategic information systems direction to be questioned. These changes included the following:

1. **Implementation of a Campus Network Strategy.** Between 1985 and 1990, the University Campus began to implement a fiber optic backbone to link the seven different schools various computer departments. The hospital's mainframe-linked terminals could not communicate easily with the campus network.

2. **Research initiatives involving non-IBM equipment.** Several departments within the School of Medicine undertook research activities involving computing on a variety of hardware platforms. Many of these initiatives required passing information from the hospital information systems, which could only be accomplished with great difficulty and expense.

3. **Changes in processing technology.** The 1985 UMMS Information Systems Plan mentions microcomputers only once, and then only for office automation. By 1989, there were over 4,000 microcomputers in use within the Medical System and the University. Many departments were demanding the ability to link their PCs to the hospital systems.

4. **Changes in the UMMS business requirements.** After the 1985 Information Systems Plan was completed, UMMS developed a long-range business plan which identified key areas of focus. None of the business requirements of this plan were directly reflected in the information systems plan.

5. **Growth of Medical Informatics at the University of Maryland.** Between 1985 and 1989, the University of Maryland at Baltimore blossomed as a center for healthcare informatics. Major initiatives in the School of Nursing and the School of Dentistry stimulated initiatives in other schools and created a higher level of sophistication and expectations among the faculty.

REEVALUATION OF THE 1985 PLAN

In 1989, UMMS found itself in a dilemma. It was only half-way completed with a five-year plan yet its original budget had been exceeded by several million dollars. It was unknown how much additional money would be required to fully implement the plan. At the same time, capital availability was restricted because of commitments to upgrade old facilities and to build new ones. The information systems planned for implementation were being criticized because their fundamental architecture reflected design technology from the 1970's. The inability of the communications architecture to access different computer platforms was perceived to be a severe weakness.

In January, 1991, UMMS suspended implementation of the mainframe-based systems, pending a reevaluation of the 1985 Plan. The Information Systems Steering Committee undertook a systematic approach to answer a series of questions concerning the 1985 Plan.

1. How much will the plan cost to complete?
2. How well does the 1985 Plan meet the business requirements of the users?
3. What alternatives exist to the current strategic information systems strategy?

Over a five-month period, a task force including nursing, ancillary departments, Information Systems, and representatives from IBM and Digital Equipment Corporation tried to answer these key questions.

Through modeling, it was determined that the answer to the first question would be an additional \$2.5-4.0 million for mainframe upgrades and disk storage alone. If the model's margin of error was as great as 25%, the cost could be as high as \$7 million. To answer the second question, a team of representatives from nursing and other ancillary departments reviewed a number of different order management and nursing systems and compared them against the mainframe software that had been purchased by UMMS in 1986. The consensus was that, while each of the systems had some benefit, **none** of the systems reviewed would meet the information needs of Nursing and the other business units. The task force recommended not installing the order management system which UMMS owned. Based upon the answers to the first two questions, the Information Systems Steering Committee determined that the 1985 Plan was no longer a realistic strategy.

Major effort was then focused on answering the last question: What alternatives are available? To answer this question, a vision was developed for what computing should be at UMMS and how it should relate to the rest of the University. The vision stated that any computer or terminal device in the hospital or on the campus should have the capability of accessing any system (if properly authorized). The vision included the ability to access newer digital imaging technologies if the end-user equipment permitted. Through the process of defining these needs, a consensus among physicians, nurses, and other departments was achieved. The UMMS vision is best described as *open systems architecture*. That is, the ability to connect a system from any manufacturer to a network and to be able to share information between it and other systems without the need for multiple complex interfaces.

For the task force, developing a plan to make this vision a reality required blending current technology with future technological promises. The reality was that, in 1990, hospital vendors were only beginning to embrace the notion that their systems should talk with each other in the healthcare arena. Most software and hardware vendors were emphasizing a proprietary approach for integration. None of these proprietary alternatives was found to be acceptable to the UMMS.

DEVELOPING AN OPEN SYSTEMS ARCHITECTURE

In late 1990, UMMS engaged Andersen Consulting to assist in developing an Information Distribution Plan based upon the results of the reevaluation project. The objective of this effort was to develop a detailed plan for how UMMS could make its vision real and, at the same time, remain within the financial constraints of the organization. Over a four-month period, a joint team from Andersen and the Information Systems staff interviewed a large number of users, researched similar initiatives in other industries, and developed a strategy for information distribution to meet the particular needs of an academic medical center. The recommendations from this project fell into three major categories: hardware, software, and organization.

HARDWARE

From a hardware perspective, there was a need for a backbone communications medium to support the various computing activities within UMMS. The team recommended implementing a fiber optic backbone because of its capacity to handle the current level of traffic and because of anticipated increases in traffic when digital imaging technology becomes more common.

To provide the connections from the backbone to the various terminal devices, the strategy includes the use of concentrators which are devices that can be configured through the use of module boards to attach a variety of local area networks and/or terminal devices to the backbone. This approach permits existing terminal devices to continue to be used, avoiding the cost of replacing equipment in order to access the network. Because of the modular design of the concentrators, changes in configurations or terminal devices simply require replacing a card in the concentrator rather than replacing the entire device.

An additional recommendation was the adoption of universal wiring standards. In the past, wiring for data, voice and video communications were managed separately. Under the new approach, a universal wiring standard was adopted so that all cabling to support voice, data, and video communications would be pulled to a single wall jack. The new standard requires that all cables be pulled back to a central wiring closet where the telephone patch panels and the backbone concentrators are located. In the first implementation of the standard in a building renovation, UMMS technicians were able to configure a variety of LAN configurations for several different departments in a matter of days rather than weeks. The flexibility of this approach enabled office moves to be accomplished quickly with a minimum amount of manpower.

SOFTWARE

The major strategic software recommendation was to adopt a standard communications protocol for the network. Because of the variety of hardware equipment in place, the team recommended the Transmission Control Protocol/Internet Protocol to address the lower level communications needs and the Health Level-7 protocol for specific applications requirements for the network. TCP/IP is a non-proprietary protocol in widespread use in academic environments and is a national standard. An additional factor favoring its selection is that it is the standard for the University network.

The HL-7 standard addressed a major concern about the increasing amount of resources being devoted to developing and maintaining interface programs between systems. By 1989, maintenance of interface programs was consuming over thirty percent of the available resources of the Information Systems department. A key element of the information distribution strategy was the concept of writing a single interface to the network as opposed to writing multiple interfaces to the individual systems on the network. While HL-7 is an emerging standard for healthcare information systems, many healthcare software vendors have voluntarily adopted conformance with it. For UMMS, six of its software vendors have pledged compliance with HL-7. Use of HL-7 interface standards enables interconnectivity to be established with other systems in a much shorter time than with non-standard systems.

In the first implementation of HL-7 at the Medical System, the ADT system was interfaced with an anatomical pathology system. The effort to write the HL-7 interface took two systems analysts four months to develop and test. In the second implementation of an HL-7 interface, medication dispensing units, which are HL-7 compliant, were interfaced with the ADT system in less than ten days of analyst time. Over time, the Medical System will replace the existing interfaces with all of its systems with the HL-7 standard to take advantage of the ease of development and maintenance.

For systems which are unlikely to ever comply with the HL-7 standard, the team recommended developing intermediate software solutions called Transaction Management Processors. Systems such as the mainframe billing system might require thousands of hours of programming to make them HL-7 compliant. Rather than change the source code of the individual non-HL-7 compliant applications, the strategy calls for developing intermediate systems that would act as translators, taking non-HL-7 transactions and converting them before broadcasting them on the network. The TMP could be either a set of software programs running on the individual host machine or a combination of software and hardware, connecting a particular system with the network.

The third major software component of the strategy is the Central Information Handler. In the future when all devices attached to the network will be intelligent, they will individually have knowledge of where specific databases reside on the network. Until that happens, there is a need for a directory on the network that knows the location and content of every database. The Central Information Handler is an index server to the network, pointing and routing transactions to their appropriate nodes on the network. In addition, it serves the function of being the auditor of the network, recording every transaction and making a copy of it, should there be a system failure on any particular node. To implement the CIH, the Medical System has chosen to develop an index-oriented database using fourth generation database and programming tools. The major effort associated with the CIH implementation is in identifying the potential users of the network and attempting to determine what their information requirements will be. Figure 1 graphically shows the overall approach.

ORGANIZATION

The final major component of the strategy focuses on the organization required to manage an open systems environment. The open systems strategy requires a different orientation for the Information Systems department. Traditionally, Information Systems was the proprietor of the computing hardware, and, by default, the owner and controller of the data which was

University of Maryland Medical System (UMMS) Information Distribution System Strategy

Strategy Recommendation

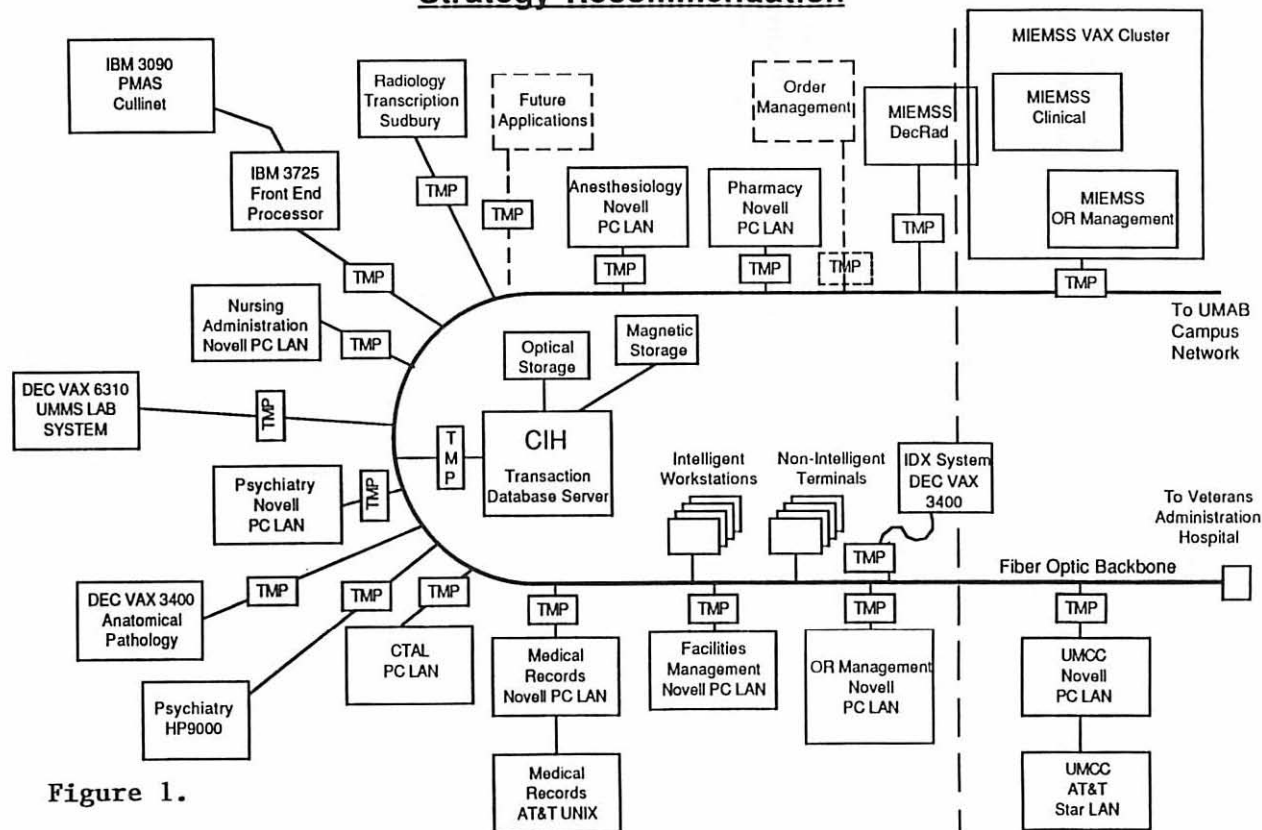


Figure 1.

stored in it. Its organizational purpose was primarily operations-oriented, while at the same time, focused on implementing new technology. Systems development activities focused on implementing systems which would meet internal standards for operating performance. User departments frequently had to compromise to meet the limitations of the information systems organization and the processing environment.

Under the open systems approach, the actual computing power is shifted to the specific applications and the end-user departments. The users have the power to select the hardware and software which will best meet their particular needs, as long as it complies with the network standards. Systems development activities shift toward a consulting role, helping to facilitate the software selection and its successful implementation. Instead of having a mainframe as the center of the the information systems, with all of its limitations and costs, the network is now the center of the computing environment.

As the shift from centralized to decentralized computing occurs, there is a corresponding shift in emphasis from data center operations to network operations. In the first applications of computing in hospitals, effectiveness of data center operations was measured by how well batch production schedules were met. When online systems were introduced in the late 1970's, the data center also became responsible for meeting batch processing objectives **and** for guaranteeing the availability on online systems. In an open systems environment, the data center operational effectiveness is almost totally measured by the availability and reliability of the network. In effect, Information Systems becomes an information utility to the organization.

This change requires the deletion and addition of functions to the traditional information systems organization. New skills and tools must be added for monitoring and diagnosing network problems. Problem resolution for users becomes infinitely more complex as the location of potential problem areas expands over an entire network. Security functions become critical as access to the network expands. Because of the ability to build the network in incremental blocks, the ongoing network planning function becomes a continuous process.

From the perspective of the traditional I.S. organization chart, network management does not create a new branch on it. Many of these functions logically fall within existing organizational divisions. The challenges of managing a network environment will focus on finding an organizational structure that will accomodate managing across a traditional hierarchy rather than vertically within it. The implementation and management of the network becomes a critical process for the entire information systems organization and will evolve over time as decentralization becomes complete.

The UMMS strategy is to maintain a high degree of flexibility in the I.S. organization and use cross-functional teams for network implementation.

BENEFITS

The development of an information distribution infrastructure and the subsequent interconnection of local area networks and other data networks offers a range of benefits to the Medical System. These benefits include the following:

1. **Cost savings on equipment investments.** This strategy permits existing equipment to continue to be used but the functionality of the equipment is enhanced by operating in a networked environment.
2. **Cost savings on equipment relocations.** The use of standards in wiring and equipment reduces the need for custom cabling to support relocations.
3. **Unification of information resources.** Users may access any information resource attached to the network from any location on the network. The long-range potential now exists to use powerful workstations to marry data and images from a variety of systems.
4. **More efficient use of computer resources.** This approach lessens the reliance on a single mainframe and diminishes the risks of a single point of failure.
5. **Cost savings through the use of standards.** Already UMMS has achieved considerable efficiencies through the adoption of the Health Level-7 standard. Instead of writing multiple custom interfaces between systems, a single set of interface programs can be written. The time required to bring up new systems in this environment drops dramatically.
6. **Productivity increases and cost savings through network proliferation.** The network strategy allows expensive peripheral devices such as printers and plotters to be shared. Because of the ability to access the network, there is a reduction in the need for duplicate efforts in data gathering. Under our long-term scenario, there will be greater convenience for our patients by being able to share demographic and clinical information between all providers of care.

7. **More efficient access to information.** A more diverse group of users will be able to access information to meet their specific needs without waiting for reports to be delivered.

8. **Greater system "ownership" among users.** The flexibility afforded by the network architecture and the use of communication standards will allow end users to play a greater role in choosing the systems that best meet their needs.

9. **Reduced risk of costly mistakes.** This strategy permits new systems to be installed in increments rather than making a major organization-wide commitment to a single vendor or system. The nature of the network encourages the development of pilot systems which can be used to demonstrate the benefits of a particular approach before making a significant financial commitment.

SUMMARY

The information distribution strategy using open systems architecture at the UMMS is a conscious recognition of trends that have been evolving over a period of years in an academic medical center. The flexibility of this approach recognizes that change will be a constant factor. The traditional role of information systems within a healthcare organization will continue to evolve as the network matures. This strategy represents a commitment by the organization to support an information distribution infrastructure that will provide sufficient flexibility to meet its needs into the next century.

Optimization of Reporting and Billing of Radiological Procedures With an RIS-HIS Interface

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Abstract

The Bowman Gray School of Medicine and North Carolina Baptist Hospital implemented an order/entry module to be maintained in the hospital information system (HIS), which was interfaced to an existing radiology information system (RIS); the professional billing program was modified accordingly. Examination data is transmitted to the RIS from ordering locations throughout the hospital. Information such as admitting diagnosis, clinical indications, and procedures are verified on terminals/personal computers prior to allowing the requisition to print. This control method of reviewing clinical indications has improved the quality and accuracy of examination history information.

Radiology coding personnel review the transcribed examination report, verify eligible charges, and encode Current Procedural Terminology (CPT) and International Classification of Diseases, ninth revision (ICD-9), codes into an electronic billing form displayed on a terminal. Compared to previous billing methods, billing by the transcribed report more accurately reflects clinical indications and related procedures and results in increased professional charges.

Introduction

Over the last 5 years the need for automated procedures within a radiology department has increased significantly. Departments have typically become more complex as a result of the evolution of imaging technology, staff increases, increased volume, and off-site imaging centers.

In addition, accurate and timely reporting has always been one of the major goals of a department's operation. Emphasis on these goals has increased tremendously, with new rules and guidelines for quality assurance protocols, Joint Commission on Accreditation of Hospitals (JCAH), and new Medicare coding/billing requirements. Computer-based information systems (CBIS) have

become a key variable in the effective management of the above conditions. It is important that the initial design of a CBIS be flexible enough to change over time to meet the challenging trends of the future.

This paper describes how our department has modified our current CBIS to meet the goals of more complete and accurate clinical information and optimization of professional charges through the use of CPT and ICD-9 codes.

RIS-HIS Order/Entry Interface

Our department designed and implemented an RIS called IMAGES/3000 in conjunction with Smith, Dennis, and Gaylord (Santa Clara, CA) in 1980. IMAGES/3000 operates on a Hewlett-Packard computer and is an application-rich system that is configurable to accommodate a large academic environment. The RIS operated in a stand-alone mode until May 1990, when it was interfaced to an order/entry module called CLINIPAC (HealthQuest, Atlanta, GA) which is part of the central HIS operating on a IBM mainframe.

During the interface planning process, it was decided that our department should strive to obtain the most complete clinical information possible related to the requested examination. To achieve this goal, we would need to develop automated procedures that would be nontraditional, as compared to the traditional RIS-HIS approach, which allowed requisitions to be printed immediately within radiology once the order was transmitted. This traditional approach did not provide the advantage we felt was needed to gain accurate control of the clinical indications of the requested exam. Once the requisition prints, it is more difficult to follow up with the ordering location if the indications do not accurately match the requested examination. The new interface was designed so that the requisition is not automatically generated once ordered. It forces each order to go through a review process within radiology. Once the order is reviewed, the radiology admission personnel can print the requisition.

When the attending physician writes an order, a nurse on the ward calls up the electronic patient profile on a cathode ray tube (CRT). The nurse selects the radiology order section which displays the technique and anatomical sections. The nurse then selects the section of interest and proceeds to identify the specific examination requested. Once the examination is chosen, a table representing 16 most frequent ICD-9 code descriptions, including an "other" category (see Illustration 1), for that exam is displayed. The user selects the ICD-9 code description, which is transferred to the clinical indications field on the display and then is attached to the interface to be transmitted to the RIS.

Once the examination order and its associated data are sent over the interface, they are received in the RIS and managed by a program called Data Validation Program (DVP). The DVP examines the transmitted file for format accuracy, and if specifications are met, it sends the order to one of seven admission stations within radiology. The admission stations are classified as follows: 1) Inpatient, 2) Outpatient, 3) Magnetic Resonance Imaging, 4) Nuclear Medicine, 5) Special Procedures, 6) Pediatrics, and 7) Emergency Room. The routing logic to the admission stations of the DVP had previously been defined on the basis of patient characteristics (e.g., Pediatrics) or specific examinations performed within the imaging rooms associated with the admission station.

The orders are sent to a CRT within the admission station module and are displayed on a priority basis. This special sequencing displays the most time-critical orders first, with less critical orders following. This predefined logic was based on priority codes developed jointly by personnel in radiology and nursing. The priority codes utilized are 1) Emergency, 2) ASAP, 3) Today, 4) Routine, 5) Timed, 6) Pre-op, and 7) Tomorrow. As multiple orders are sent to a specific admission station, the DVP acknowledges the priority codes selected by the ordering location and sorts them appropriately on the radiology admission display, highlighting with a blinking status bar all emergency orders. Once orders are displayed, the admission personnel selects the order with the highest priority, which explodes onto the display all pertinent patient demographics, requesting physician, ordering location, requested examination, admitting diagnosis, clinical indications, and special conditions (see Illustration 2). The information is reviewed for completeness, accuracy, and justification. Assistant and chief technologists help to oversee the review process and insure order validation. If order discrepancies are perceived, a telephone call to the ordering station allows us to communicate with the person who initiated the order within minutes after receiving it. If a mistake is identified, the radiology admission personnel have the flexibility to modify the order within the RIS with the verbal approval of the ordering location. This system eliminates the need for retransmission of the order by the nurse.

Once the order information is satisfactory, the admission personnel will identify on the screen that the order has been checked by typing in "Y" in a field represented by the statement "QC? (Quality Control) (Y/N)."

The order can be immediately printed onto a requisition or can be delayed if the order is for a future date. All previously approved orders for future dates will be printed in a batch mode one minute after midnight on the day that the order is requested. This feature eliminates the need for the admission personnel to manage preprinted requisitions for future dates of service.

As previously stated, this automated quality control review function has been functional for almost 2 years and has produced more timely and accurate order information than with the previous manual method. Prior to order/entry automation it was virtually impossible to question the validity of the order because of the difficulty of getting back to the nurse or physician who created the order in a timely manner.

Professional Billing

In the fall of 1989, we commissioned a consultant to review our professional pricing master and change control systems. This step subsequently led to a complete audit of our charges in 1990. The identified problems were as follows:

- 1) A significant number of orders originating from the CLINIPAC order entry system did not contain accurate clinical indications relating to the requested examination. This mainly was attributed to the CLINIPAC system requiring the nursing staff to manually input the clinical indications. As detailed in the earlier discussion on the RIS-HIS interface, this manual input has been replaced by electronic selection of appropriate ICD-9 clinical indication descriptors.

- 2) The professional charge component was directly tied to the examination code that the technologist bar-coded at the time of the procedure, regardless of what was later documented by the dictated report. The consultant documented four primary types of errors carrying through the system: special procedures coding, in which the hospital's system of procedure codes was based on room usage and the technologist then had to select from a separate professional CPT code; errors of omission, in which billable charges were missed because technologists are not first and foremost billing personnel or coders in their orientation; errors of commission, especially in cases where the technologist might "down code" or "no code" a billable procedure in the interest of protecting the patient; and institutional errors resulting from rigidities in the interfaces that could not pass CPT modifiers or multiple codes. The consultant also informed us about a future Medicare directive that was being formulated to require the identification of the interpreting radiologist on each claim, thereby eliminating any global or section-related default.

The department made three strategic decisions in 1990 to address the issues outlined above:

- 1) It was decided that the professional billing component could not be optimized if we continued to have a one-to-one default from the technical procedures code to a professional CPT code. Therefore, we hired billing

personnel who were trained in radiology professional coding techniques to review and code the dictated reports.

The benefits of this conversion have been threefold: a) increased accuracy of procedural coding, which has not only improved reimbursement but has also improved cash flow, as fewer claims have been returned or questioned; b) resolution of the "interpreting radiologist" issue, as coding now takes place only after report approval; and c) reduced audit exposure, because physician services cannot be billed in the absence of a dictated report.

2) The department evolved the professional pricing master from a hospital-oriented ledger and procedure format to a CPT-formatted ledger.

3) In late 1991 we initiated the development of a professional billing module associated with the current RIS. This strategy separated the technical and professional components and provided an opportunity for the CPT coding staff to utilize automated procedures for billing instead of the manual methods of filling out coding forms for later input into the claims program operated by our central billing department.

In April 1992 the automated professional billing module was implemented. The coding staff can now request the system to produce a list of previously approved patient reports that have met all requirements for billing. The staff can input the requisition number into a display on a CRT or personal computer, and all the predefined professional billing information appears on the screen for review. The staff has the option of reviewing the dictated report on-line or having it printed out. The on-line capability simulates a "windows" effect by allowing the user to toggle back and forth between the report and previously defined billing data. This system is quite efficient for the coding personnel. The coder reviews the comprehensive information, now consisting of the following elements: approved report; CPT code was cross-walked from the technical code that was bar-coded during the patient tracing process; ICD-9 code, which was selected by the ordering location; fees; approving radiologists; date of service; and ordering location. The staff either accepts the information or has the flexibility of modifying or deleting the previously captured data based on the review of the report. At the end of the day, the verified professional transactions are converted to a magnetic tape and sent to the central billing department for processing. Since the radiology transactions already contain the appropriate CPT and ICD-9 codes, they only have to be verified for patient demographic integrity. This eliminates the previous coding delays by the central department and allows the radiology claims to get out faster than previously, with increased accuracy.

Conclusion

The automated procedures of the order/entry and review process have provided an environment that enables both the nursing and radiology staffs to insure increased accuracy of clinical indications relating to the radiographic examination. This information has provided continuity among admitting diagnoses, clinical indications, and requested examinations, which are ultimately tied to the dictated report for quality assurance measures.

Compared to previous billing methods, billing by the transcribed report more accurately reflects clinical indications and related procedures and results in increased professional charges. The coordinated electronic operations including input of ICD-9 codes at the nursing station, charge capture during the patient tracking process, and the flexibility of modifying CPT and ICD-9 codes based on an on-line dictated report, have allowed the billing function to become more efficient and have virtually eliminated improper charges.

Continuing education has become a major factor in the accuracy of both the order and the professional charge. Periodic meetings with the nursing and radiology admission staffs allow potential problems to be addressed and emphasize the value of accurate clinical information. Education must also be ongoing between the radiologists and professional coders. Continual review of methods of radiologist interpretation, coding techniques, and current and future Medicare requirements must be conducted regularly for charge optimization.

NC BAPTIST HOSPITALS, INC 04/10/92 13:19
 DOE, JOHN WFUP 0612127 CHEST - PA & LATERAL
 REASONS FOR EXAM - RADIOLOGY SELECT ONE REASON

 SARCOIDOSIS
 MALIGNANT NEOPLASM OF BRONCHUS AND LUNG, UNSPECIFIED
 MALIGNANT NEOPLASM OF BREAST (FEMALE), UNSPECIFIED
 OTHER MALIGNANT LYMPHOMAS, UNSPECIFIED SITE
 CHRONIC ISCHEMIC HEART DISEASE, UNSPECIFIED
 AORTIC VALVE DISORDERS
 CONGESTIVE HEART FAILURE
 ACUTE UPPER RESPIRATORY INFECTIONS OF UNSPECIFIED SITE
 ACUTE BRONCHITIS
 PNEUMONIA, ORGANISM UNSPECIFIED
 ASTHMA, UNSPECIFIED TYPE, WITHOUT MENTION OF STATUS ASTHMATI
 CHRONIC AIRWAY OBSTRUCTION, NOT ELSEWHERE CLASSIFIED
 UNSPECIFIED PLEURAL EFFUSION
 POSTINFLAMMATORY PULMONARY FIBROSIS
 SYSTEMIC LUPUS ERYTHEMATOSUS
 UNSPECIFIED CHEST PAIN
 END OF DISPLAY

OTHER ENTER MASTER
 VSRC50Z CLINIPAC USER: ELAINE P. BOLES TERMINAL ID: L445

ILLUSTRATION 1

QC REVIEW

PAT ID	123456	NAME	DOE, JANE	
DOB	11/04/36	OTHER ID	MARY	SEX F
LOC	R0927A	REF DR	1022	USER D JAMES
REQ NO	9876543	DOS	04/13/92	RRI 07
	ORDER DATE-TIME	04/10/92 15:19		ROUTINE
INDICATIONS	F/U PT WITH BREAST CA			
DIAGNOSIS	AML/BREAST CA			
	EXAMS			
BONE SCAN				
	QC? (Y/N)			

ILLUSTRATION 2

SESSION 13

Expert Systems/Teaching

Chair: Atsuko Heshiki

A PC-Based Educational Training Program for the Radiological Sciences

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I. Introduction

The body of knowledge that comprises the Radiological Sciences is expanding at a rapid rate, as a direct result of ongoing technological developments in a myriad of imaging modalities. For those who have completed their basic education and have specialized in a particular area, continuing education is more of a necessity than a luxury. Students of the Radiological Sciences must deal with volumes of information coming from a number of sources, as well as learn the fundamental principles that constitute the science of imaging. With limited amounts of time to devote to these studies, the student must organize study time as efficiently as possible, otherwise the material to be learned will become overwhelming.

Many students will set out to learn only the information pertinent to the next exam. The problem with this method is that material often remains unlearned for future standardized board or registry examinations. In an effort to combat this self-defeating system, the authors have developed a PC based program. The use of PC's in education is well documented (6, 7, 10, 16, 30, 31, 34). The purpose of the program, named Making The Grade (MTG), is to assist the student and/or professor through the process of organizing the material to be learned. MTG is based upon an educational method known as Concept Mapping (14, 18, 19-21, 23, 29, 32, 33), which is similar to our method called Thought Mapping (TM) (27).

The first goal of the project involved deriving thought maps from the classroom material, and presenting the material to the students with this new system. This was first attempted in 1982, and met with little resistance from the students and other faculty. Concurrent with this portion of the project, the authors were also involved in a computer software project called Making The Grade (26, 27). Here, the aim was to develop a generic testing and evaluation program for use in any topic by student and professor. This project resulted in a software program that allows the user to either develop multiple-choice type questions or to use standardized databases for the purpose of determining one's understanding in a given topic. This program has been further updated to comply with the TM system.

The second goal of the project involved teaching the students how to make their own thought maps when presented with material in class. This portion of our project necessitated that the students review teacher-created thought maps, and then create their own. The students found difficulty with this approach initially. However, after time and training, the students accepted this new task as a normal part of what was expected of them.

The third goal of our project was aimed in two directions: (1) application of the system in topics other than the sciences, and (2) preparation of a manuscript instructing the reader in the methods of TM. The first point was addressed by questioning instructors and students majoring in the social sciences, and having them use the TM technique for their studies. The response from this part of the project was very positive, and so we progressed to part 2, the manuscript.

In 1985, the authors used the TM technique for a lecture for Radiologic Technology Students about to take their Registry Examination (12, 13). We developed thought maps that could be used both to review the necessary topics in a lecture format and as a source of review materials. In 1988, computerized versions of TM and MTG were employed in a series of lectures to Radiology Residents concerning magnetic resonance science (22). In 1991, the main test taking and evaluation module MTG was selected by the United States Environmental Protection Agency, in conjunction with the American Public Health Association, for use in a Radon Knowledge Assessment Project. This revised version will be made available to school children in the junior high and high school age group to allow them to assess their own understanding of Radon. This computer program will work with both IBM-PC's and Apple Macintosh PC's. Work on this project is continuing at the Eastern Regional Radon Training Center, under the direction of Alan Appleby, Ph.D., located at Rutgers University (24). Demonstration programs for the Radiological Sciences and the Radon Knowledge Assessment are available from the authors.

II. Materials and Methods

MTG is intended to be used in one of two ways: (1) as a test taking tool, in which the program will run through a series of questions in a category or categories selected by the user. Here, separate statistics are presented in the final score as to the total correct and incorrect responses, and the ability of the user to make a correct response on subsequent attempts on the same question. Or (2) as a study modification and test development tool. The program can be used to show the student the manner by which exam questions are designed. This is meant to focus the student, so that better study habits will be a resultant of using MTG. Through a separate utilities program, the student may enter the various categories, thus helping to emphasize the relationships that comprise the Radiological Sciences or any other selected topic. After this information has been entered, the student may design and enter examination questions with a developer's toolkit. These questions may either

go into a bank of questions for other students to use, or may be evaluated by a professor. The emphasis here is placed on self-help, whereby the troubled student may be lead toward better performance by studying in a more efficient manner. It is maintained that in encouraging the student to become involved in the actual formation of questions, the overall organization of the major concepts of the subject may be better edified.

MTG is based upon the Vee Heuristic and Concept Mapping (5, 19) models of learning. We have adapted the latter method to our Thought Mapping (25) process. TM is a study method that allows a student to fully delve into a topic, discover the interrelationships that comprise the subject, and graphically display key points.

III. Results

In 1988, a study was performed to determine the attitudes of students towards the use of Thought Mapping. Phase I of the project used radiation therapy technology students as the target population. This part of the project started with the development of a questionnaire that contained three thought maps based upon electron linear accelerator design and associated physics, with the maps being of increasing complexity. Of 124 questionnaires distributed, 94 were returned, and were scored according to Norcross (15, 17). The results of Phase I showed that students were willing to try using thought maps for their note taking in class, as well as in creating thought maps for their own learning. They indicated a greater willingness to combine information found in their texts with maps from class than those students who used linear note taking only. Their was a strong preference for a simple thought map as opposed to a complex map.

Phase II of this project involved giving a test with multiple choice questions and essay questions to a control group of radiation therapy technology students and a group who had been instructed using thought maps. The test was on the same topic as in phase I. Phase II tested whether thought mapping could influence grades on tests in a positive manner. Students who had used thought mapping scored 11 percentage points higher, on the average, on exams than those who had used linear note taking, both on the multiple choice and the essay part of the test. Subjectively, the students who used thought mapping stated that they enjoyed a higher level of recall than they had previously experienced with their linear note taking, due to the increased interaction that thought mapping requires of the student.

Phase III involved placing multiple choice questions into a module of MTG for Radiology Residents. The topic selected was computed tomography and magnetic resonance physics. The test was administered to a group of residents who had been instructed with thought maps, and a control group who had never seen thought maps. In this case, the residents were not required to make thought maps in their studies. Subjectively, the residents who used thought mapping indicated that they appreciated

a multiple choice test that was modelled after their classroom instruction. Alternatively, the residents who were instructed without thought maps liked the format of the test and the completeness of their scores, and requested more testing modules for practice.

IV. Discussion

MTG and TM have proven useful in providing:

- 1) an analysis of the strengths and weaknesses of each student with regard to retention of the subtopics presented in class. An effective study regimen is therefore a natural result.
- 2) an analysis of the overall strengths and weaknesses of the class as a whole. Effective review sessions can then be designed. This also may provide focus for the teacher with regard to his or her own individual teaching method.
- 3) indication of each student's strengths. If a student cannot erase an imbalanced performance by focussing attention to defined weaker areas, then perhaps an inherent propensity to do better in certain areas is the reason. This type of knowledge can be useful in career planning (30).
- 4) an organized assembly of subtopics in the form of a student designed test (MTG) or an interconnected graphical diagram (TM). When a map is provided to the student upon introduction of the subject matter, not only are the interrelationships between subtopics made clearer, but the student knows the ultimate destination. When a student designs a test, he or she is reiterating the subtopic interrelationships as well as defining the limits for the topic under review. The increased interaction is consistent with the time worn "99% perspiration, 1% inspiration" salvo.

V. Conclusion

A knowledge assessment and study modification program has been developed for use in both the classroom and the home. The goal of the program is to allow the student to delve into the radiological sciences by discovering underlying interrelationships that comprise the topic, at the student's own rate of data assimilation. While the measurable outcome displays higher test scores, the important resultant of using MTG and TM is a better understanding of the principles of the radiological sciences, with greater long term usage of the learned material.

VI. Acknowledgments

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development of this project (17).

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Application of a Feedforward Artificial Neural Network for Pattern Recognition in Medical Images

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INTRODUCTION

Lung cancer is one of the most common and lethal cancers. Its possibility of cure depends critically on its detection in the initial stage, when the tumor is small and localized. However, this is a difficult task for the radiologist. A computational system which alerts the radiologist about the possible existence of these lesions would facilitate its early diagnose.

Some methods for the detection of nodule type structures by means of conventional image processing using schemes based on their geometric properties are described in the literature. The solutions presented are based either on the use of Hough's transform in order to extract circular structures with the later action of a classifier over the properties that were extracted^{1,2}, or on the elimination of the anatomic background and the application of circularity, size and growth tests over the regions resulting from thresholding the image with different thresholds^{3,4} or by means of the comparison with templates or patterns which are predefined through the so called 'localization techniques'⁵.

Our proposal for approaching the task of detecting nodule type structures on digitalized chest X ray images is very different to the solutions found in the literature. The system is basically structured in two blocks: detection of regions which are 'suspected' as being nodules by means of artificial neural networks or connectionist structures and later knowledge based refinement of the process and diagnostic evaluation. Several authors have proposed the use of neural networks in medical image processing with promising results^{6,7,8}. In this work we present a computational tool based on the use of artificial neural networks or connectionist structures for the automatic recognition of nodules. The approach to these problems with these structures is reduced to an adequate training process for the network, aimed at the identification of the patterns of interest. This work describes the methodology and preliminary results obtained when applying a Multilayer Perceptron Network (MPN) to tasks of finding nodule type structures on digitalized chest radiographic images. The main advantages of this alternative with respect to classical processing are inherent to the specific characteristics of the network we propose, basically, its easy computational

implementation, power and strength of the learning algorithm, the lower computational times required for the analysis of the images once the network has been trained and its good characteristics with respect to the generalization of its response to patterns which are different to the ones used in the training process and its better tolerance or reduced sensitivity to noise.

METHODOLOGY

The starting radiological images are digitalized by means of a camera computer system (Dec- μ VAX II/IPS Kontron) with a spatial resolution of 512×512 pixels, 256 grey levels and with a pixel size of 0.55mm.

Our objective consists in the detection of nodules on these images, for which we have used artificial neural networks. More specifically, the type of network used was the MPN, shown in figure 1. However, to approach this task in images with this size would mean an excessive complexity for the network, as it would have to detect structures with sizes in the 50×50 pixel range, and this would mean the implementation of a network with 2500 inputs in the first layer leading to an excessively complex learning process. Consequently, to overcome this problem, we have reduced the images to an eighth of their original size. As the complete system is structured in two levels, one of them aimed at the detection of 'suspicious regions', this size reduction does not mean a loss of information. The objective of the network is to detect those conspicuous regions, minimizing the number of false positives and avoiding false negatives. The second block projects this information onto the original image, triggering specific processes, knowledge based processes, in order to confirm or not the suspicion and perform a diagnostic evaluation. Bearing these considerations in mind, we have prepared a network which acts on overlapping windows of the reduced image to be analyzed with a size of 14×14 pixels (a little larger than the size of the structures to find) and which generates a single output (one neuron in the output stage). Therefore, the network will present 196 inputs to its first layer, associating to each one of them the grey value corresponding to the pixels covered by the window.

The first step followed has been to train the network "teaching" it to recognize the desired structures. This process was carried out by means of the backpropagation algorithm⁹: The network is presented with a set of training patterns and is given the desired output for each one of them. Following an iterative procedure, the weights are modified based on an error function (error between the desired output for each pattern and the real output provided by the network), repeating this process until the convergence criterium is met.

In our case we have carried out a training of the network by means of the learning method proposed by Silverman and Noetzel⁸ for the analysis of ultrasonograms for the detection of choroidal tumors. This training process adapted to our problem is illustrated in figure 2 and is carried out as follows: We start from a

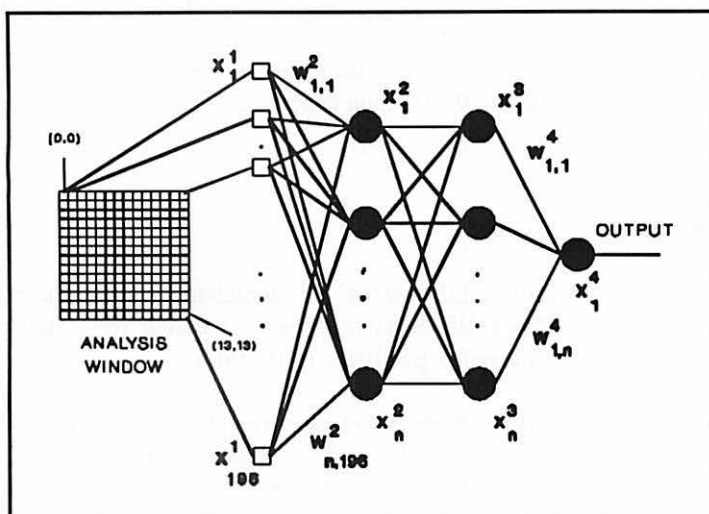


Figure 1: Multilayer Perceptron Network (4 layers).

w_{ji}^l represents the weight associated with connection between element i of layer $l-1$ and element j of layer l .

digitalized lung radiograph (figure 2.a). The nodules present in this image were delimited by a radiologist (marking their perimeter) using computer graphics interaction tools. From these marked image, another image of the same size in which the nodules are represented by means of masks over a background with a uniform grey level is generated (figure 2.b). This way, a "mask" image of the nodules is generated where the grey level associated to the area occupied by the nodules is 204 and that of the background is 51, which, after normalizing, become 0.8 and 0.2 respectively, taking those which were considered the optimum values in [8]. From both images we carry out the true training process consisting in projecting on the inputs of the networks the pixels associated with 14*14 pixel regions extracted from the real image (figure 2.a). To each one of the windows we associate a desired output equal to the grey value of the central pixel of the equivalent window on the mask image. A complete scan of the trained image and a reiterated projection of this image on the network will configure its weight structure until the convergence criterium is achieved. Figure 2.c. shows the results from applying the network on the training image once the network has been trained. This image shows the correct training of the network on the selected image.

The training of the network also pursues the discrimination of structures which could easily be misinterpreted, as they may present a contrast variation with respect to the anatomical background very similar to that of the nodules (for example ribs, contours, etc). Another advantage of the process we present consists in that we not only obtain as a result the possibility of existence or not of nodules on the image, but we

also obtain an approximation to the morphology of the nodular structures. This allows us to have more information in order to make the final decision that will "refine" the response of the network and which will even permit the production of a diagnostic/prognostic evaluation of the confirmed nodules.

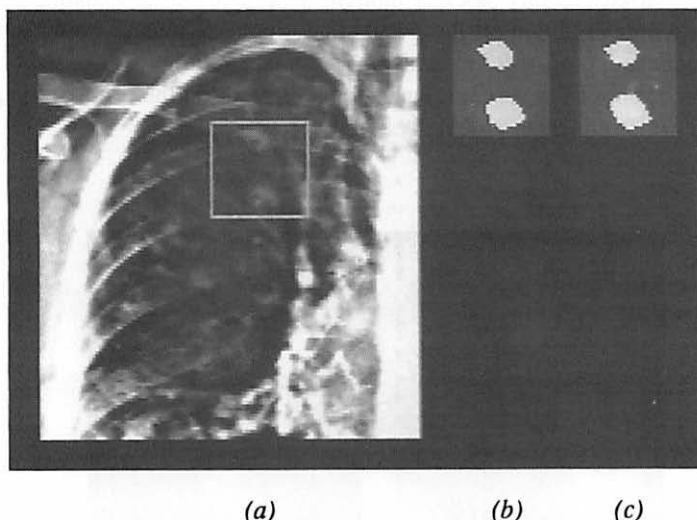


Figure 2: a) Training image. b) mask image. c) results from applying the network to the image after training.

One aspect we must also point out is the selection of the network size. A compromise solution between complexity, specificity and generality was obtained with a network formed by two hidden layers and six neurons in each of the layers.

RESULTS

In order to illustrate the result of applying the trained network onto new images, we have chosen the image represented in figure 3.a on which we have marked the existing nodules.

Figure 3.b shows the results obtained when we applied the previously trained network on the image. We must point out that all the true nodules are detected although there are certain structures in the image which the network interprets as nodules (F in the figure) and which really correspond to structures in the hilar zone and a large area at the top part of the image which corresponds to a lesion area. The

time required for the analysis of the image was 30 seconds. The training lasted one day in a SUN station. The preliminary results obtained reflect the efficiency of the structure we propose (worse results were obtained using artificial training patterns¹⁰).

It is important to point out that our priority objective is to achieve a maximum sensitivity as this block is thought of as a previous scanning of the image from which we must obtain all the events that are suspicious of being lung nodules. After this focalization on specific areas of the image, a knowledge based block for the confirmation or not of the previous suspicion will work on the original image with the original size, improving the global specificity.

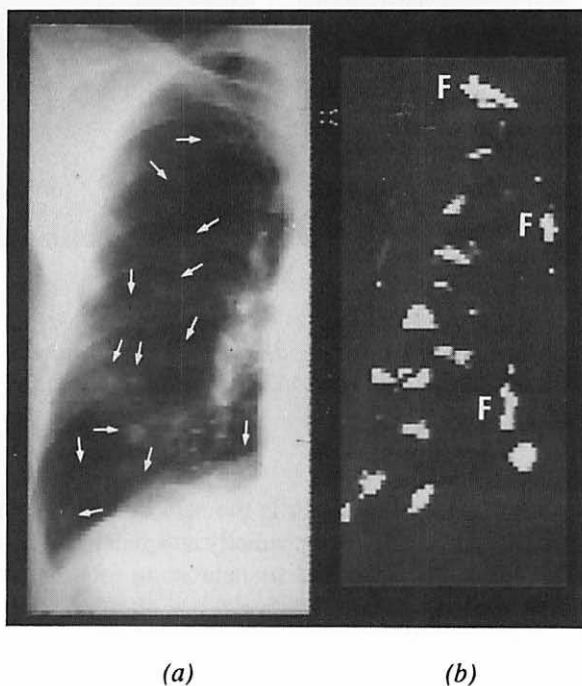


Figure 3: a) Explored Image. b)- Results of the exploration.

ACKNOWLEDGEMENTS

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Computer Simulations of X-Ray Generator Control Panels

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Using a Macintosh computer and a program called Authorware Professional (Authorware, Inc., 8500 Normandale Lake Blvd., Suite 1050, Minneapolis, Minnesota 55437), computer simulations of various x-ray generator control panels have been developed. The purpose of these simulations is to enhance the conventional teaching of these concepts to student technologists. Authorware Professional is an advanced multimedia authoring system which combines graphics, animation, and interactive branching based upon student responses. Using these capabilities, simulations have been designed to resemble and function like their real world counterparts with appropriate user controls and displays. Realistic x-ray generator technique controls have been simulated on the screen and may be independently manipulated by the student who can observe the effect of changes on simulated instrumentation.

A primary role of a radiographer is the manipulation of expensive, high technology x-ray equipment. The mechanical aspects of a radiographic examination must be mastered early by the new

student. It is important that the new student become as comfortable as possible with the physical manipulation of the x-ray equipment. Once this is accomplished the beginning radiographer can concentrate on the other important skills that must be learned such as patient care, positioning, technique, and film quality. Generally speaking, the student who masters the essential skills of equipment manipulation early does well in the more professional aspects of radiography. On the other hand, the student who struggles and fails to quickly learn to handle the x-ray equipment often has trouble moving to more advanced skills.

A first step in mastering equipment manipulation is being able to identify the generic components of a radiographic system. A beginning radiographer who has visited a radiology department can be overwhelmed by how different each radiographic room looks. The differences are similar to the automobile, which is manufactured with seemingly endless variations in outward appearance. There are different models, sizes, shapes, dash board layouts, and instruments. However, each has a motor, steering column, brake pedal, speedometer, fuel gauge, etc. The same is true of different types of radiographic equipment. They appear very different in shape, size, and layout, but they all have common components. The common components in a radiographic system are the x-ray tube, collimator, x-ray table, control console, and tube stand. The one generic component with the most variations is the control console.

The control console is the device that gives the operator control of the x-ray machine. It is one of the most complicated components of the radiographic imaging system. The first encounter with an unfamiliar control panel can be mind boggling even for the experienced technologist. There is tremendous variation between manufacturers in the appearance of control panels or even between different models from the same manufacturer. Control panels have evolved from basic knobs, push buttons, switches, and meters to sophisticated computer screens with digital readouts.

One of the first hands-on skills that the beginning radiographer performs is setting x-ray techniques on the control panel. The panel has the generic controls that the new student must learn. These are the on-off switch, kVp controls, mA controls, timer control, and the rotor exposure switch. To aid the student in the mastery of interacting with the control panel we have designed computer simulations of two different, yet common types of x-ray generator consoles, one a Siemens (fig.1) and the other a Picker (fig. 2). The two control panels differ in a number of ways. The following features and variations between the two have been incorporated into the computer simulations.

On the Siemens console, kilovoltage is selected by turning a knob with available increments ranging from two on the low end to nine on the high. The Picker provides two columns of pushbuttons, one for major kilovoltage in 10 kV increments, the other for

minor kilovoltage in 1 kV increments. Because the Siemens generator is of a falling load type, it allows the operator to specify the selection of mAs only, again by turning a knob. The Picker generator allows free selection of mA and exposure time, each represented by an array of pushbuttons. All pushbuttons on the Picker generator are mechanically interlocked so that only one can be selected at a time.

Another difference between the two units is the indicator arrays provided to the operator. The Siemens console provides two unlabeled lights. A green light indicates "Ready" and goes out when an unavailable technique is selected. A red light goes on only during exposure. All indicators on the Picker generator use text. Various messages in red indicate an unavailable technique. No message indicates "Ready". A green message indicates that the rotor is up to speed and a black-on-white message appears during exposure.

A two-position handswitch has also been simulated. The handswitch on these two units are mechanically interlocked so that the exposure switch can only be operated after the rotor switch is engaged. Since this mechanical operation could not be simulated by either the keyboard or mouse, the program allows the operator to manipulate the handswitch by clicking on special buttons on the screen. A graphic on the screen shows a hand pressing on the switch and displays indications as displayed on the generator.

The computer simulation is meant to enhance conventional teaching. Using the simulation, students may manipulate controls and observe responses in an unsupervised setting. In addition the student is allowed to work at their own chosen pace independent of the availability of equipment. The computer simulations are enhanced with help screens which explain various features of the x-ray control consoles.

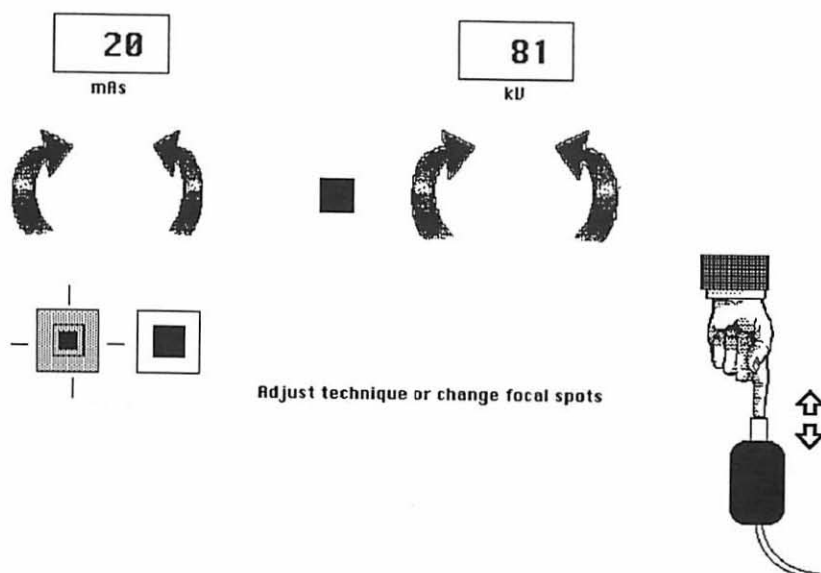


Figure 1. Siemens x-ray generator console

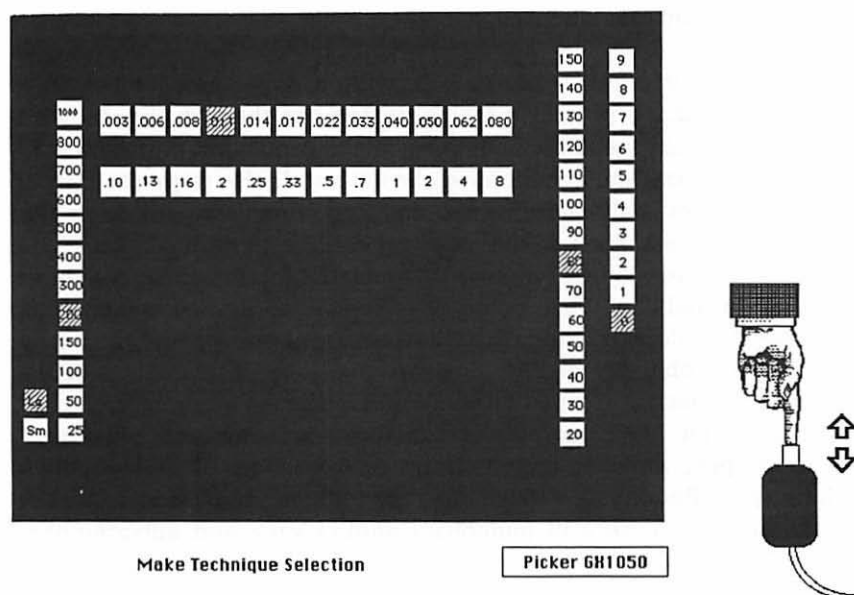


Figure 2. Picker x-ray generator console

Personal Computer Interactive Program for Interpretation of Ventilation/Perfusion Lung Scan

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The authors developed an interactive personal computer program for interpretation of ventilation/perfusion lung scans. The data base for this computer program was 275 angiographically proven ventilation/perfusion lung scans. These were collected by the authors during the period 1979 through 1981 at Washington Hospital Center and The George Washington University Medical Center, Washington, D.C. The authors analyzed the outcome of this data base and derived an interpretation scheme which is a modification of the well known Biello (1979) scheme [1]. The addition to the Biello criterias was incorporation of segmental equivalent approach, "stripe sign," and extent of ventilation abnormalities [2].

The interactive program is written as a questionnaire to a nuclear medicine physician which guides him through the decision making process based on the findings of the ventilation/perfusion lung scan and the current comparative chest x-ray. It also requests clinical probability of pulmonary embolism and provides guidance for quantitative estimation of this prior probability. The final result is a Bayassian curve plotting outcome of ventilation/perfusion lung scan vs clinical probability. Final outcome of ventilation/perfusion lung scan is numerical along with the verbal description of normal, low, moderate and high probability of PE. Software also allows evaluation of the mode of optimal therapeutic and diagnostic management including indication for platismography contrast venography, and pulmonary angiography, anticoagulant therapy or cessation of anticoagulant therapy. Recommendations are based on published data of risk/benefit analyzers of pulmonary angiography and anticoagulant therapy. The data is presented as outcome of utility probability (utility analysis) which evaluate diagnostic probability of pulmonary embolism and consequentive probability of effect and complication of diagnostic and therapeutic procedure.

This decision tree was used by the authors in prospective diagnosis of ventilation/perfusion lung scans of studies obtained at the University of Maryland during 1991-1992 (Table 1) [3]. It showed that out of sixteen cases with diagnosis of high probability of pulmonary embolism, all sixteen were positive on pulmonary angiography. Out of 30 patients with low probability of pulmonary embolism, only one patient was positive on pulmonary angiography (3.3%). This is a significantly higher accuracy than was reached by the authors in a previous study (1982) where outcomes of ventilation/perfusion lung scan were studied based on visual evaluation of scans. In 1979-80 (Table 2), 61 out of 67 patients with high probability report (91%) were positive on pulmonary angiography and two out of 35 patients with low probability report were positive on pulmonary angiography (5.7%).

We found that this interactive diagnostic program is very useful in everyday routine practice. We currently use this interactive program for our studies, as a teaching aid with third and fourth year medical students and diagnostic radiology residents.

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TABLE 1

Accuracy of V/Q Lung Scan**1990-1991**

V/Q Report	Pulmonary Angio		Number of Positive Pulmonary Angio for PE	% of Positive for PE
	N	%		
Normal	2	0.8%	0	0
Low Probability	30	5.5%	1	3.3%
Moderate Probability	23	30.3%	4	17.4%
High Probability	16	17.5%	16	100%

TABLE 2

Accuracy of V/Q Lung Scan**1979-1980**

V/Q Report	Pulmonary Angio		Number of Positive Pulmonary Angio for PE	% of Positive for PE
	N	%		
Normal	2	0%	0	0
Low Probability	35	15.4%	2	5.7%
Moderate Probability	22	17.7%	11	50%
High Probability	67	48.9%	61	91%

Status Report on an Expert System for Radiologist Scheduling

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INTRODUCTION

Two years ago we reported on a rules-based expert system for determination of optimized call schedules and work rotations for large radiology group practices. The current version accommodates 40 radiologists, 30 work locations, and seven call rotations. We will now describe our experience since then involving over twenty practices, and the modifications engendered in our program by that experience.

There are two components of the scheduling problem that are in fact relatively independent: (1) determination of call; and (2) assigning the daily work slots. The call scheduling portion has proven to be extremely robust, and has undergone only minor modification.

Most of our efforts and improvements in the interval have been in the area of optimizing the daily work schedule, primarily by using AI (artificial intelligence) techniques which will be described in detail later. Other significant changes include the transition to a new user interface using Turbo Pascal's object oriented TurboVision and an integrated schedule editor for ad hoc modifications.

IMPROVEMENTS

Practice Customization

Early on in this project it became apparent that individual practice needs demanded tailored modifications. The vast majority of these resided in the section that determined the daily work assignments. We erroneously hoped that after a dozen or so clients, that the modifications

would begin to repeat themselves. Unfortunately, our experience has been more along the lines of: "if you've seen one practice, you've seen one practice." The required modifications never "completed the circle" and some were so specific that any attempt to incorporate them into a truly generic version of the program was not realistic.

Therefore we confronted the common problem of needing to maintain client specific modifications in the face of version enhancements. We were able to accomplish this difficult task by the use of compiler switches, specific to each client, in combination with carefully written and encapsulated modifications for that client. In this way, we are able to maintain a single set of source code for compilation and delivery that contains all users' modifications. This greatly simplifies release of new improved versions to all clients that include their specific modifications.

Call Scheduler Enhancements

Various combinations of weekend and weeknight call rotations were simplified with the following concepts. A "major" call rotation is one that contains any portion of a weekend, even one night. A "minor" rotation includes any combination of weeknights exclusive of Friday. This division resulted from the fact that the rules of eligibility for any portion of a weekend are essentially the same, especially regarding the constraints of requested weeks off and spacing between call.

The call procedures for both major and minor call were modified to "N call depth." That is, the procedures can compute any number of non-conflicting call rotations provided that there are enough people to staff each of them. The call solution is driven primarily by the call structure and personnel in each rotation, and the time off requests.

Furthermore, modifications were made to the input screens and procedures to allow the user to specify exactly the number of call assignments for each individual in each rotation, and verify that the total matched the number of weeks being scheduled. (Allowance is made for specifically assigned dates, usually used to cover holiday weekends.)

To allow weeknight call to be assigned proportionally, a system of weighting factors was implemented, assigning a "value" to each night

assigned. This has been further enhanced by using iterative techniques to drive the solution to the exact proportions desired.

Finally, we have implemented a definition of "Special Sets" of radiologists. Their use in the call section of the program is to satisfy the increasing demand for subspecialty coverage. A common example is that of a practice that has a first and second call rotation. However, only some of the radiologists are "CT capable." Those individuals are designated as a Special Set, and the call solution routines will check the already computed first call radiologist for this expertise, and if he/she is not in the Special Set, then it will require that the to-be-determined second call radiologist be a member of the Special Set.

Work Schedule Optimization

Several areas were enhanced to optimize the daily assignments. First, iterative techniques similar to those used for weeknight call were implemented to drive the assignment of free days off service to the desired proportional distribution.

Second, the introduction of Special Sets of individuals for subspecialty coverage, i.e. Interventional or MRI capable radiologists greatly enhanced the quality, sophistication and acceptability of the daily work assignment solution. The most common conflicting constraints are the demands to give everyone their full share of allotted time off, yet insure that the daily subspecialty needs of the practice are met. For example, our practice has six interventionalists, and needs three every day. The first task of the work solution is to distribute excess (or non-clinical) free days off service. However, if three interventionalists are away at a meeting, then, in order to satisfy the needs of the practice, no free days should be given to any of the three remaining interventionalists that week. Special Sets are checked, with an associated integer limit value, to satisfy these constraints for Interventional and MRI. Temporarily "missed" free days are made up by the program at the earliest opportunity.

Third, a powerful method suggested by one of our clients, and implemented with little difficulty from the basic scheduling tools that we have developed, is that of rotations that are to be equally shared. This

has become a favored feature for several practices for dealing with both desirable and relatively less desirable tasks. The roster rotation scheme was modified such that, at the specified interval, for example one week, the order of the roster is adjusted in ascending order of prior assignments to that task or location, so that the individual with the fewest to date bubbles to the top.

The most difficult modification that we have implemented is the following: A practice has two groups of assignments, at two different facilities. Dr. A and Dr. B cannot work together. Now, if Dr. A or Dr. B is assigned to the first facility a given day, then it is trivial to block the other. However, if neither are assigned to the first facility, then some overriding constraint must come into play to cause one of them to be assigned to the first facility, otherwise by default they will both be assigned to the second.

Although we initially found this request humorous, we quickly stopped laughing. First, it was very difficult to implement. Second, that difficulty reminded us, somewhat discouragingly, of how far we have yet to come in easily creating systems that simulate human experts. A human expert has no trouble with the concept described above, because human "manual" backtracking is so easy.

Once the work section of the program has determined the distribution of excess free days, subject to the subspecialty coverage needs defined by the Special Sets and associated limit parameters, it remains to determine the specific assignment of who works where. For example, ten radiologists can be assigned to ten different slots in as many as $10!$ (3,628,800) ways a very large number, and a very large tree of possible solutions to search for the optimum. And that is only for one day of a one year schedule for a medium-size practice. Obviously, an orderly, efficient method is needed to search this set of potential solutions for one that satisfies the constraints in some optimal sense.

THE SELECT FAIL ALGORITHM:

To summarize from the last meeting, once our program determines the correct set of radiologists available to work a given day, by number and subspecialty skill (days off determined by needs of equality and

subspecialization), the specific job slots or rotations are filled by a two-dimensional prioritization method. First, the positions must be ranked in order of sensitivity or importance (e.g. MR or Interventional over routine outpatient films). Second, there is a prioritization of who is assigned or capable to work a certain position. This individual ranking can be constant (Dr. A always before Dr. B), can rotate on a set time interval (Dr. A, Dr. B, Dr. C then next week Dr. B, Dr. C, Dr. A), or can rotate based upon equality (the Dr. with the fewest assignments to date goes to the top of the list).

If one establishes these priorities for one's practice (not an easy political task in itself), enters them into the program's data file through the interactive screens, and computes a schedule, then the following problem occurs, with increasing severity in a heavily sub-specialized practice: Depending upon the particular combination of requested vacation and time off, and program assigned excess days off, even subject to Special Sets described above, "holes" will appear in the daily work assignment schedule. These holes arise more frequently for lower priority slots, and slots that have fewer individuals on their roster available to work. In summary, the problem occurs because too many of the available radiologists have been "pulled" or used for higher priority locations.

Borrowing from Prolog the techniques of backtracking we implemented in Pascal a procedure to deal with this over-constrained problem in the following way: search (orderly) for a solution that violates the two-dimensional prioritization in the least harmful way. This was accomplished by the following algorithm:

1. Analyze the "hole" slot to find the intersection of the sets of all those available to work that day and those in the roster for that slot
2. Backtrack up the job slot assignments to find the first individual in that set but already assigned to a higher priority position
3. Re-assign that radiologist to the "hole" slot
4. Re-select the slot that was raided, and reselect all slots back down to the "hole"
5. Discard any solution that creates a higher priority "hole"

This scheme works quite well, and eliminates the vast majority of the holes in a typical practice with well-designed rosters. However, it does not solve the problem completely, so an obvious next step was to make this procedure re-entrant: that is, if a higher priority hole is created at first pass, then re-enter to try to eliminate that hole by the same technique, etc. This in fact will virtually eliminate the "holes" for any reasonably designed set of priority rosters. The example below shows a typical week's first pass schedule (a), and re-entrant selectfail solution (b).

SELECTFAIL EXAMPLE:

(a) First Pass, No Selectfail

WEEK 10					DO1	JC1	JC2	JC3	SM1	MM1	SM4	SM2	SM3	VC1
ASSIGNMENT:					1ST	2ND	3RD							
SAT	1/25	JPY	WPS	MWD										
SUN	1/26	JPY	WPS	MWD										
MON	1/27	REM	WPS	MWD		JLS	JPY	WJH	MJG	MEB	REM	WPS		CAK
TUE	1/28	MWD	WPS	MWD		JLS	MJG	WJH		JPY	REM	WPS	MEB	CAK
WED	1/29	MJG	WPS	MWD	MEB	MWD	WJH	WPS	JLS		JPY	MJG	REM	CAK
THU	1/30	WPS	WPS	MWD	WJH	JLS	MWD	REM	MJG		JPY	MEB	WPS	CAK
FRI	1/31	WJH	WJH	MEB	JPY	MJG	MWD	JLS	WJH		WPS	REM	MEB	CAK

(b) After Re-entrant Selectfail

WEEK 10					DO1	JC1	JC2	JC3	SM1	MM1	SM4	SM2	SM3	VC1
ASSIGNMENT:					1ST	2ND	3RD							
SAT	1/25	JPY	WPS	MWD										
SUN	1/26	JPY	WPS	MWD										
MON	1/27	REM	WPS	MWD		JLS	JPY	MWD	MJG	MEB	REM	WPS	WJH	CAK
TUE	1/28	MWD	WPS	MWD		JLS	MJG	JPY	WJH	MEB	REM	MWD	WPS	CAK
WED	1/29	MJG	WPS	MWD	MEB	MWD	WJH	WPS	JLS		JPY	MJG	REM	CAK
THU	1/30	WPS	WPS	MWD	WJH	JLS	MWD	MEB	MJG		JPY	REM	WPS	CAK
FRI	1/31	WJH	WJH	MEB	JPY	MJG	MWD	JLS	WJH		WPS	MEB	REM	CAK

Note: Direct your attention to assignments for Mon and Tue. The "holes" are at jobs SM3 and SM1. (MM1 is a mobile magnet, not staffed on Wed, Thu or Fri.)

SUMMARY

We have described enhancements developed over the past two years and added to our basic scheduling program to enable it to perform better in an over-constrained environment. The improvements have been made at

the suggestion of, and in response to, the needs of our clients using this program in the field. These techniques include numerical iterative methods, set arithmetic methods, and AI backtracking techniques borrowed from Prolog. In a sense, this program has surpassed the concept of an expert system in that it can solve for practices that are becoming impossible to schedule by manual methods. In this economic and technical era, radiology group practices are becoming larger and more subspecialized. The task of computing call and work schedules, particularly with the constraints of subspecialization, is becoming overwhelming.

Determination of a daily work schedule for a subspecialized practice is an exercise in finding a satisfactory and in some sense optimal solution to an over-constrained problem. We have described the AI methods added to this expert system to selectively violate the priority scheme that we presented two years ago, in order to decrease the number of unfilled "holes" in the daily work assignments. This algorithm generally honors the priorities specified by the user, without being overly restrained by them.

It should be noted that many of the features that we have added are computationally intensive. In particular, the "select-fail" procedure, especially in its re-entrant form, and the iterative techniques for day off and weeknight call determination, can increase the computation time by almost an order of magnitude. Users still bound to XT technology can expect calculation times approaching one hour for a one year schedule for a 24 radiologist practice. However, we now assume that our clients are on a 386 or 386SX platform, and we take advantage of the available speed to compute more optimal schedules.

In closing, although we have come far, it should be noted by one of the examples cited, that we still have some distance to go to match the flexibility of the human expert. Developing truly generic programs for solving these types of problems remains a significant challenge.

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TFile:

A Microcomputer-Based Radiology Teaching File Manager

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INTRODUCTION

Virtually every radiologist or radiology department maintains a teaching file of interesting, unusual, or classic cases. Traditionally this is a logbook, or in more ambitious instances, a card file sorted by anatomy or pathology. TFile is a user-friendly microcomputer program with significant advantages over such paper-based systems. It is implemented as a HyperCard stack on an Apple Macintosh computer. It was designed for quick entry and retrieval of case data. A modified version of the American College of Radiology (ACR) Index for Radiological Diagnoses is incorporated into the system for easy entry of systematized anatomy and pathology terms and code numbers. In addition to patient name and ID number, a free form "notepad" is included for each case allowing maximum flexibility in data entry. The user may search the teaching file for any term or combination of terms. Cases can be marked for printing for a hard copy reference.

TEACHING FILE SYSTEMS

For many years radiologists have recognized the

need to record cases of interest. These may include classic findings of a particular disease process, as well as the rare or unusual presentation of a given disease, or even the "I don't know what it is" case. Such a record is valuable in education both formal and personal. It may also be an important resource for research. When maintained over the course of years it may form an important bank of knowledge and collective memory. Such an amount of data will however quickly become useless unless there is a way to easily record and retrieve it.

As early as 1926, various coding systems were proposed to index teaching file cases for ease of retrieval and cross-reference (1). Often these systems have used some combination of numbers or letters to code for both the type of pathology and the anatomic region or organ system involved. Probably the most widely used system today is the ACR Index for Radiological Diagnoses which provides a systematic scheme to code for virtually every anatomy or pathology term used in radiology (2).

While such methods provide a systematic means of coding cases, retrieval may be difficult. A logbook is an easy, quick and cheap method to record case comments. Retrieval of any but the most recent cases is difficult however due to the lack of organization other than by date of entry. Card file systems allow organization by ACR code for anatomy and pathology, but make it difficult to easily find a given individual case of interest.

Computerized database systems offer significant advantages over such paper-based methods. Large volumes of case data may be recorded and rapidly searched. We have previously described XFile, a teaching file system designed for an IBM compatible personal computer (3). TFile is a teaching file database for use on an Apple Macintosh computer which offers additional capabilities with a user-friendly interface.

TFILE

TFile was written for use with HyperCard 1.2.5 (Apple Computer, Cupertino, CA) and is implemented on a Macintosh IIfx (Apple Computer) with 4MB of RAM and an 80 MB hard disk. HyperCard is a software authoring system designed to allow those without extensive programming experience to create useful applications. It uses the metaphor of a stack of cards which may be viewed one at a time. Cards may contain data in various fields. Buttons may be placed on the cards to perform certain actions when clicked with the pointer by the user.

TFile stores each teaching file case on a separate card (figure 1). Fields are provided for the ACR anatomy and pathology terms and code numbers. For ease in sorting cards the ACR code is modified slightly to expand each code to a five digit number. Fields also exist for patient name and ID number. A scrolling field is provided for freeform data entry about the case. This "notepad" may include any information about the case

including date and type of exam, a description of pertinent findings, clinical history, laboratory data, etc. This section allows maximum flexibility in saving important case information, allowing the user to personalize the system to his or her needs. Two hidden fields are present on each card. One records the date the case was entered into the system. The second holds the name or personal code of the person who entered the case. This permits subsequent searches for only one's own "personal cases."

USING TFILE

The user may easily browse the entered cases by clicking on the next or previous buttons to view the corresponding cards (figure 1). This becomes most useful in conjunction with the sort button which permits the stack to be sorted by anatomy or pathology terms so that similar cases will be grouped together. The stack may also be sorted according to date the case was entered or by the person who entered the case, thus grouping one's "personal" cases together.

One of the most important features of TFile is the ability to quickly search for any particular term or terms entered into the stack. This includes the anatomy and pathology terms and codes, patient name or ID, or any term entered into the case "notepad." If two items are entered into the find dialog only those cards containing both items will be found. Clicking on the Find Again button will locate the next instance of that item or items.

TFile	
Anat	72500 = STOMACH LESSER CURVATURE
Path	25300 = ULCER - PENETRATING NICHE
Name	John Q Public
ID	1234567890
Case	UGI barium swallow 8-5-91 Classic findings of a benign penetrating ulcer 3cm crater projects outside normal lumen Radiating mucosal folds in spokewheel configuration Patient is a 34 year old male with a 6 month history of epigastric pain
Mark card Print marked New case Find Home Sort Previous Next Find again	

Figure one. TFile case card. Buttons along the bottom control various stack functions when clicked with the pointer.

TFile	
Anatomy	
Click on desired term from list below:	
72000 = STOMACH 72100 = GASTRIC FUNDUS 72200 = GASTRIC BODY 72300 = GASTRIC ANTRUM 72400 = PYLORUS 72500 = STOMACH LESSER CURVATURE 72600 = STOMACH GREATER CURVATURE 73000 = DUODENUM 73100 = DUODENUM FIRST PORTION, BULB 73200 = DUODENUM SECOND PORTION (DESCENDING) 73300 = DUODENUM THIRD PORTION (HORIZONTAL)	
Chosen term: 72500 = STOMACH LESSER CURVATURE	
Find Cancel OK	

Figure two. ACR Index anatomy term selection card. Clicking on desired item chooses it for inclusion on a new case card.

As the user browses through the cases he or she may mark individual cards for subsequent printing.

Entering new case information was designed to be quick and easy. Since the ACR index is built into the system, the user need not memorize codes or have to consult a book of codes. When the New Case button is clicked, the user is taken to a special card with a scrolling list of anatomy terms and codes (figure 2). The user simply clicks on the desired term which is displayed for confirmation below the main list. Since the list is lengthy, the user may use the Find button to directly locate the desired item, rather than having to scroll through the entire list. When the anatomy choice is confirmed the user is presented with a similar list of pathology terms. Ten different pathology lists are available, one of which is automatically chosen to correspond to the ten major anatomy groups. For instance, if the anatomy term is stomach, only the list of gastrointestinal pathology terms is shown.

When both terms are chosen a new card is created with both items entered automatically. Also automatically entered is the date of entry and the name or personal code of the user. The patient name, ID, and case notes may then be entered by the user onto the card. If desired, additional information may be entered into the case notes at a later time. By using a unique user selected term (for example, F/U) in the notes section cases can be easily retrieved for addition of follow-up results.

SUMMARY

TFile is a radiology teaching file database for recording and retrieving interesting case data. It was designed to permit easy data entry (including ACR terms and codes without having to consult a book of codes). The user can quickly browse through the system and may sort or rapidly find individual cases by using a user-friendly interface. Falling prices for microcomputers have made it feasible to have such a system available in the reading room to enable maximal usage and utility. Such a system has the capability to make a large body of information accessible and therefore useful.

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SESSION 14

**Information Management
and Teleradiology**

Chair: Philip G. Drew

A Proposed Deployment of a Teleradiology System to Relieve a Manpower Shortfall

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The radiology department of the University of South Alabama College of Medicine currently provides primary diagnostic services to three general hospitals and two outpatient clinics within the city of Mobile. The immediate purpose of the University of South Alabama Radiology Support (USARS) system is to achieve a more timely match of the patient to the most appropriate radiological sub-specialist (e.g., neuroradiologist, pediatric radiologist, etc.) by electronically transmitting over a wide area network (WAN) high resolution (both contrast and spatial) images and image supplements between diagnostic work stations located at each of the five medical treatment facilities (MTFs) of the USA hospital system (USAHS)^{1,2}. The five MTFs consist of three general hospitals and two outpatient clinics located within the city of Mobile. The inter MTF distance varies from ~2 to ~12 miles. Each of the MTFs is currently linked via a leased T-1 line to the University Computer Center, located on the USA campus, which provides HIS services to each MTF. See Figure 1.

The diagnostic images to be transported include conventional film/screen radiographs (CF/SR), computed tomography (CT) and magnetic resonance images (MR). The CF/SR images must be digitized prior to transmission. The CT and MR images must be captured at full dynamic range of the modality prior to transmission. The first operation requires a laser digitizer at each site. The second requires a digital interface at each digital modality. Each work station will support primary diagnosis from a one- or two-monitor soft copy image display (SCID). High fidelity hard copy image displays (HCID) also may be produced on demand at each work station on an existing local 3M laser printer. The teleradiology system must provide for remote printing of HCs via the existing laser printers. The digital image storage requirements of the USARS system that was sought by the present invitation to bid was to provide only for the images to be transmitted over the system for primary diagnosis. That is, it is a stand-alone teleradiology system that was immediately required rather than a PACS, i.e., a simple stand-alone system for rapidly transporting diagnostic images, image supplements, and patient data and diagnostic reports over the WAN between USARS diagnostic workstations at the five sites.

In the typical clinical diagnostic scenario the images for a patient admitted to any of the hospitals or outpatient clinics of the USAHS will be read by the most

experienced subspecialist in the USA Radiology Dept. by transmitting, as required, the patient images over a WAN to any one of three hospitals and one outpatient clinic. Therefore, the USARS WAN does not require a centralized or "hub-and-spoke" configuration, with a centrally located concentrator or data repository ("file server"), but could be served by a distributed or "race track" configuration. Each workstation hard disk should have at least 1 gigabyte of memory and the WAN should provide a T-1 level of carrier service. One possible configuration for the teleradiology system was to combine local Ethernet LANs at each site with a T-1 WAN.

Laser digitizers and digital imaging modalities (CT and MR) must be able to be interfaced to the USARS teleradiology system. These devices must be capable of communicating with the system using standard protocols; ACR-NEMA is the standard of choice. Open standards which are based upon ACR-NEMA, but which use TCP/IP over Ethernet for lower layer communication are acceptable if the following conditions are met:

- 1) The protocols that implement the lower layers of the standard are open, freely available to all, and have been implemented by multiple contractors.
- 2) The contractor will commit to upgrade to the ACR/NEMA standard over TCP/IP when ACR-NEMA version 3.0 is published.

If either a protocol based upon ACR-NEMA or the ACR-NEMA protocol is used, all primary diagnostic information shall be encoded in the standard ACR-NEMA elements. The use of shadow elements to encode data which is specified as primary diagnostic information is not allowed. The ACR-NEMA standards are not explicitly required for the WAN connections.

In addition to the above requirements the USARS system must also support an "On-Call" feature that will provide for transporting (24 hours/day) diagnostic quality images over public telephone lines (19.2 kbps) to the private residences of up to two diagnostic radiologists who may be "on-call".

There were three principal options for the contractors to address in their respective bids. Contractors are expected to include quotations for each of the several options. Two of these options were:

- 1) Integration of the USARS teleradiology system into the extant USACSC T-1 WAN vs a separate USARS T-1 WAN designed by the contractor. The University stipulated that the extant T-1 WAN could be used only in the clear-channel mode; it could not be sub-channelled.
- 2) Contractor to perform or sub-contract all site preparation, including renovations, as well as retrofitting and/or upgrading of extant equipment (including cabling and interfacing to digital modalities) as required by the contractor's bid response vs contractor to provide adequate specifications and directions to University to accomplish the same required renovations, retrofits, and/or upgrades within the same time frame and under contractor supervision.

The contractor could also propose alternative options which the University would consider if those appeared to be in its best interest. For every option the contractor would have complete responsibility for providing a turn-key installation for the USARS system. A turn-key installation is the complete installation of all USARS system equipment and accessories to include all utility extensions, connections, and upgrades and facility renovations and modifications so as to provide a complete and fully useable system without any additional intervention by the University.

The invitation to bid was based upon the technical part (section C) of a larger document, Medical Diagnostic Imaging Support (MDIS) System, Acquisition Document prepared for the US Army and administered through the US Army Engineer Division, Huntsville, AL.³

We shall describe the different solutions to the problem proposed by the seven vendors who presented responses to the invitation to bid. The vendors, who are all well-known "players" in the PACS/teleradiology field, will be identified only as vendors A, B, C, D, E, F, and G. The vendors varied in their experience in the teleradiology field: A-D have considerable experience; E, F, and G have less; however, F is a major "player" in the computer field; G is a major "player" in the diagnostic imaging field.

The previously referenced USA T-1 WAN provides HIS services to each of the potential MTFs. See Figure 2. This WAN employs IBM's System Network Architecture (SNA), and is composed of T-1 links between various communications processors (Front-End Processors, or FEPs in IBM parlance) and token-ring bridges. Host computers on this network include two IBM mainframes and IBM AS/400 and DEC PDP/11 minicomputers. Terminal cluster controllers provide service to over 500 terminals and microcomputers; there are also several OS/2 LANs connected to the WAN.

Each of these T-1 links operates in clear-channel mode, *i.e.*, the full T-1 bandwidth of 1.544 megabits per second (mbps) is used by the data communications link. The alternative approach is to divide the T-1 channel into discrete fixed-speed subchannels, *e.g.*, 56 kilobits per second (kbps). The use of clear-channel avoids the problems of load balancing among control units and smooths out response time variations at different terminal devices. Similarly, maximal bandwidth is available for high-speed activities on demand. Clear-channel also reduces the numbers of digital service units, modems, and data lines which must be monitored.

The SNA protocol predominates in larger data processing operations, reflecting IBM's position in that environment.⁴ It is a proprietary, hierarchically organized networking architecture. For the network based on an IBM host, it provides substantial control and management capability. However, integrating other protocols into an SNA network can pose substantial difficulties, as the bid responses indicated.^{5,6}

Factors facing any systems integrator/developer in the choice of networks (or, indeed, any hardware and software components) include compliance with official (such as IEEE or NEMA) standards, compatibility with proprietary but de facto standards (e.g., IBM SNA, DECnet, Novell Netware, etc.), vendor support, performance, vendor's in-house resources and competency, targeted environment, and cost considerations. In some cases these factors conflict. Not surprisingly, vendor responses to the request to incorporate the USA WAN varied - as did the networking implementations chosen.

It was important that the University be able to exploit the extant T-1 WAN for several reasons: 1) Installation charges for a separate T-1 network would exceed \$6000, with recurring annual line charges exceeding \$25,000; 2) the Department of Radiology would need to assign staff and develop the skills necessary to interact with communications carriers and troubleshoot line problems, a service which the Computer Center already provided; 3) Patient data and other services related to the Medical Center HIS were accessible from this network, and could later be integrated into the Radiology Information System; 4) The HIS network already penetrated widely into the Medical Center facilities, offering the possibility of delivery of radiology information to primary care areas; 5) Current usage of the WAN is on average less than 10% of total bandwidth, with maxima not exceeding 30%. Computer Center and Radiology management were of the opinion that the proposed wide area tele-radiology traffic was sufficiently episodic in nature and low in volume that no trunk lines would be significantly degraded.

Potential perceived drawbacks to this approach were: 1) The requisite hardware and software components to integrate vendor equipment into the SNA WAN were of an uncertain cost and availability for those vendors using either their own proprietary protocols or Novell Netware or TCP/IP for wide-area connectivity services; 2) The University projections of traffic patterns could prove incorrect, and in fact the HIS activities on the network would be degraded; 3) Teleradiology transmissions would be significantly degraded from T-1 speeds, either by the HIS traffic or by the particular design of the University SNA network; 4) Vendor experience in many cases was limited to dedicated communications networks (T-1 or 56kbps), and integration with SNA could present technical and cost uncertainties for these vendors. The latter point proved significant in the pre-bid evaluation phases. The University frequently found a disparity in understanding of the network issues between vendor marketing and technical support staff, and discovered that it was essential for University technical staff to communicate directly with vendor networking support specialists.

Vendors were also allowed to provide alternate bids based on several options, including 1) Exploiting other common carrier provided options, such as switched high-speed service, on-demand packet switching, ISDN, etc; 2) "hybridizing" the University

T-1 WAN, i.e., adding separate circuits compatible with vendor's network to by-pass incompatible legs of the SNA WAN but use the compatible segments. See Figure 3.

No vendors elected either of these options, whether for technical reasons or unavailability in the Mobile area. Only vendors E-F submitted solutions that used the University T-1 WAN. These vendors already supported IBM's Advanced Program to Programm Communication (APPC) specification, which is a component of SNA and fully compatible with the University network.⁷ All bids are described in Table 1.

After receipt of all bids, conversations with the vendors B-D suggested the following reasons for their failure to exploit the University T-1 WAN in the clear-channel mode as was required by the bid:

- 1) Traffic issues arising from contention with existing network users.
- 2) The potential performance degradation due to the number of bridges and protocol conversions that would be required.
- 3) Bridging the image traffic over the extant IBM SNA network would be a development project, which, although feasible, would require indeterminate amounts of time and would require the University to absorb most of the non-recurring engineering costs of development.

From the perspective of these vendors, points 1) and 2) made it difficult to predict the performance of the teleradiology system and to decide whether it could - or did - meet the bid specifications. Although the University stated a willingness to accept some uncertainties in this regard, there was vendor reluctance to absorb the non-recurring engineering costs and the risks incurred in a "one-off" operation. It is worth noting that these vendors were the most experienced in actual teleradiology implementations.

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Table 1. Vendor Responses		
Vendor	Bid Amount #	Salient Features
A	No Bid	
B	\$ 350,000	1 2* 3* 4
C	\$ 950,000	1 2* 3 4
D	\$ 950,000	1* 2* 3* 4*
E	\$ 1,100,000	1 2 3 4
F	\$ 1,000,000	1* 2 3* 4*
G	\$ 1,450,000	1* 2* 3* 4*

- # To Nearest \$50,000
- 1 Turnkey Operation.
- 1* No Turnkey Operation.
- 2 Uses USACSC T-1 WAN in clear channel mode.
- 2* Requires separate T-1 or 56 kbps WAN, or subchannelizing USASC WAN.
- 3 Includes digital interfaces to CT, MR.
- 3* Does not include digital interfaces to CT, MR (video only or no interfaces)
- 4 Includes 19.2 kbps "On-Call" teleradiology system.
- 4* Does not include 19.2 kbps "On-Call" system. (56kbps or no "On-Call").

InterMTF Traffic Pattern for USARS System

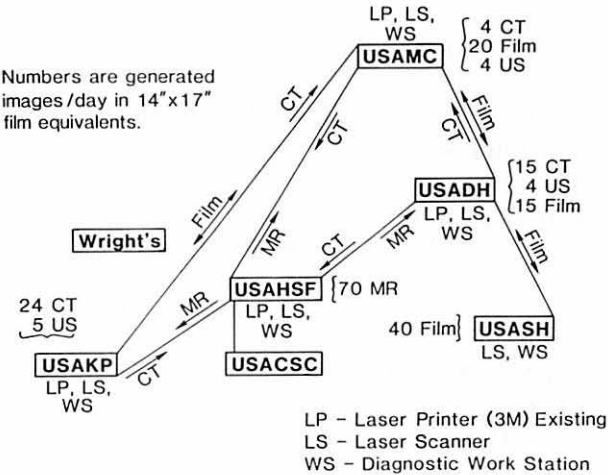
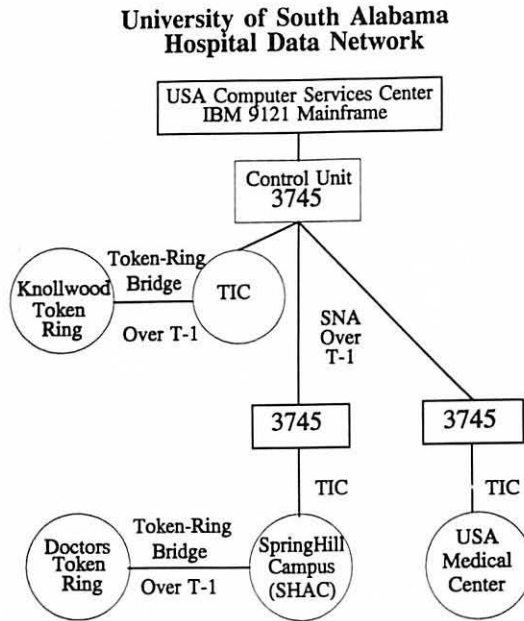
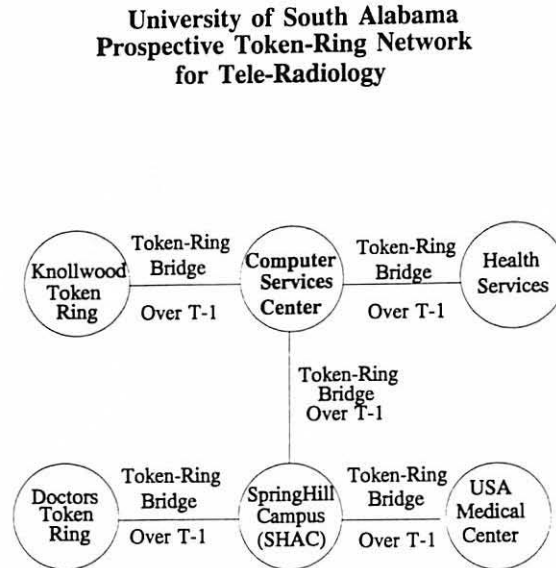


Figure 1. Topology of USARS System



IBM 3174 Cluster controllers are attached to TICs at each site; end-user 3270 terminals are attached via coax.

Figure 2. USA CSC WAN



Radiology would provide T-1 links from SHAC to CSC and USAMC, and bridge to USA Token-Ring

Figure 3. Possible Alternative WAN

Experience with a Computer Driven Moveable Carousel for the Storage and Retrieval of X-Ray Jackets

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INTRODUCTION

The storage and retrieval of x-ray jackets are very important functions of any Radiology Department. Traditionally, this function has been accomplished by using fixed shelves or movable high density shelves, which have their respective advantages and disadvantages.

Fixed shelves require more space than movable shelves, since they have to be separated by aisles for access to all the jackets, but have the advantage of lower capital cost. They are generally used in most Radiology departments. Movable shelves are very economical in terms of space, but tend to be more expensive and slow down the process of retrieval by not allowing simultaneous access to all the x-ray jackets. Their use is, therefore, limited to departments which are small or relatively slow.

In this paper, we describe the development of a novel movable carousel system which provides high density storage of x-ray jackets with random access for rapid retrieval of the jackets. This system was designed and installed four years ago at Kaiser Permanente Medical Center Orange County which is a 200 bed hospital performing 150,000 x-ray procedures per year. As far as we are aware a carousel system had never been used previously in a Radiology department for the storage of film, although they are routinely used in dry-cleaning establishments, and have been used in other industry for the storage of parts.

DESCRIPTION OF THE FILE ROOM

The file-room is 1200 square feet and was designed to hold 150,000 x-ray jackets, which are filed in six revolving carousals. A section of the file-room is shown in Figure 1.



Figure 1: Overall view of a section of the file room showing two movable carousals, and two work stations back to back.

The carousals move on tracks, shown in figure 2, which are bolted to the floor and are driven by electric motors at the rate of 60 ft/min.

The floor plan of a representative carousal is shown in figure 3. A carousal can be larger or smaller than the one shown depending on the size and geometry of the file room. Each dark box in the floor plan (figure 3) represents a section. Each section has five bins stacked one on top of the other, as shown in figure 4. Each bin is slightly larger in height and in depth than a standard x-ray jacket, and is 22 inches wide. Figure 3 thus shows 22 sections, containing 110 bins and 2,420 linear inches of filing space. Taking an average filing density of 45 jackets/linear foot, the carousal shown will hold approximately 9,100 jackets.



Figure 2: Track bolted to the floor on which carousel rotates.

The movement of a carousel is powered by an electric motor which can be controlled manually by a controller, or by a computer. At the time of installation the location of each section of a carousel relative to the location of a work station is programmed into the controller. The

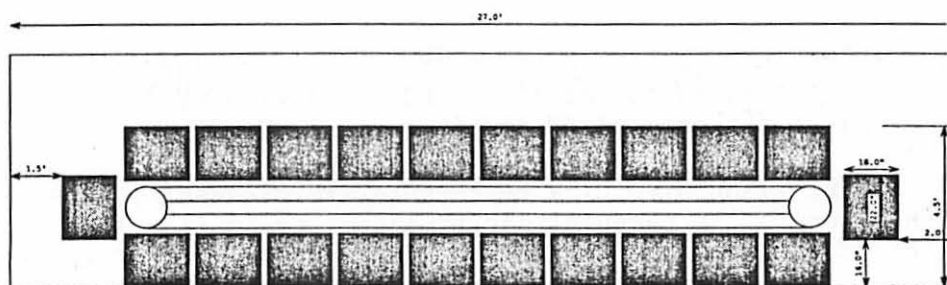


Figure 3: Geometry of a typical carousel.

controller is then able to retrieve any section and bring it to the work station when requested to do so.

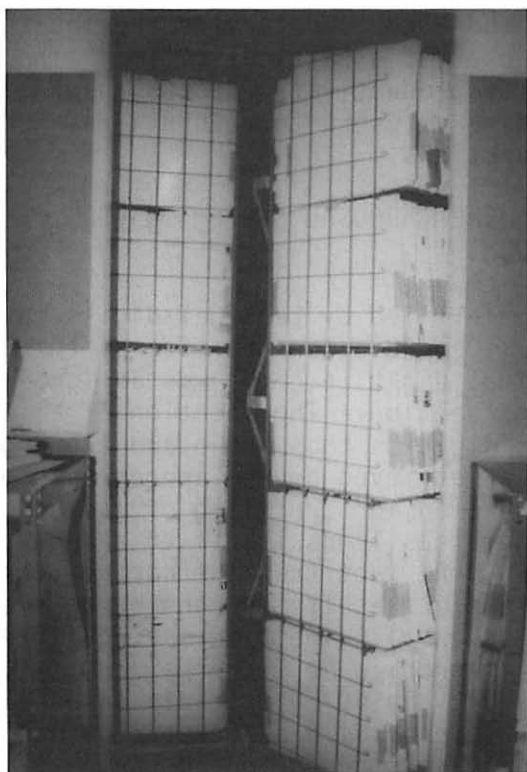


Figure 4: Side view of two sections of a carousal showing five bins in each section, stacked one on top of the other.

THE COMPUTER SYSTEM

The computer used to operate the file-room is an IBM 386 SX PC purchased from Advanced Office Concepts Inc. The main computer can operate multiple stations in the file room and there are three stations in the file room and two remote stations in the department. Each x-ray jacket is bar-coded with the patient's medical record number, and the location of the jacket either inside the file-room (in the carousal) or outside the file-room (e.g. in a doctor's office, in reading room, technician station etc.) is then tracked by the computer which has a data base incorporating all the jackets and their most recent locations. Whenever a jacket is moved from one place to another its current location is entered into the

computer using bar-codes. Remote stations are used for this purpose and also to determine the location of a particular jacket at a particular time. The computer also generates staff productivity reports, user lists, waiting lists, reminders to users to return x-ray jackets among many other functions.

ADVANTAGES OF THE CAROUSAL SYSTEM IN TERM OF THE OPERATION OF THE FILEROOM

Jackets are filed by terminal digits in the bins of the carousal. Depending on the size of the file room, a certain terminal digit (e.g. 01) is assigned to all or to a portion of a section. The location of all jackets with this terminal digit is thus known and the appropriate jackets can be retrieved or the appropriate bins brought to the work station for refiling of jackets. The carousal system thus lends itself to a centralized work station. Also, the fact that the carousal brings a jacket to a station results in considerable saving of time (and thus money). The time saving is achieved in the following manner:

Tandem retrieval: By using multiple carousals, a file clerk can retrieve or file a jacket from one carousal while other carousals are bringing the next jackets to the work station. The entire time of the file clerk is thus spent in retrieving or filing and not in walking up and down the aisles. A single clerk can retrieve, sort and deliver to various locations 600 to 700 jackets per shift of eight hours, by entering into the carousal system requests for jacket location.

Simultaneous functions: When one is walking to a jacket as in the case of fixed shelves, one cannot perform additional functions. However, when a jacket is being brought ot the station, the file clerk can perform additional functions such as writing, organizing, matching, researching etc.

Pacing: A file coming to a station at 60 ft/min creates an urgency similar to the ringing of the telephone. It establishes an even but quick pattern of retrieval that can naturally push personnel to work at a faster rate without a sense of fatigue.

The centralized work station has the following advantages:

1. Keeps personnel at their work-station as much as possible and maintains their focus and concentration. It reduces the need to "re-orient" themselves each time they return to their work area. It also reduces the universal "aisle idleness" syndrome.
2. Provides optimum work-station utilization by providing all the tools required for the job at a central location. This includes forms, pens, new jackets, labels, slips etc.
3. Provides a view of the entire operation at a glance and thus greater management control of the staff in a non-threatening fashion.
4. The system naturally lends itself to assigning two or more carousals to one work-station manned by the same person each day. This creates accountability with pay-backs in terms of problem-solving and problem prevention.
5. Misfiles are reduced since the staff is focused, is accountable, and since the correct bin is brought to clerk by the computer.

COMPARISON OF SPACE REQUIREMENT

As shown in figure 3, the spacing between the moving sections of a single carousel is 18 inches. When two carousals are placed side by side, they can be spaced 15 inches apart, and it is this feature which provides approximately 25% space saving when compared to fixed shelves. Fixed shelves generally require a 3.5 ft. aisle between shelves for access. The carousel system cannot compete with movable high density shelves in terms of economy of space, but it allows rapid retrieval of files not possible with the movable high density system.

COMPARISON OF COST

Cost of six carousals containing 34 sections each was \$112,000. The cost of an equivalent fixed shelves system is \$56,000. The carousel has many advantages over the fixed shelves as discussed above. There is also a saving in operational cost. According to a management

engineering report the greater efficiency of the carousal system has resulted in a net saving of 0.7 FTE (full-time equivalent) in personnel cost --- approximately \$23,000 per year. The system, therefore, pays for itself in a few years.

The cost of the computer, software, color monitors, three remote stations, laser printers, bar-code readers, tape drive for backup etc. was \$61,000. Most of the features of the computer can be used with a fixed shelf system as well, with considerable advantages over a manual system of record-keeping.

RELIABILITY OF THE CAROUSALS

The initial concern with the design of this system was whether it would carry the weight of the x-ray jackets, which is considerable, without breaking down. Our experience is that the uptime is greater than 99%.

CONCLUSION

The carousal is an ideal system for a busy hospital. It is reliable, cost effective, economical in terms of space, reduces misfiles and improves the productivity of the staff.

MIPL: An Image Processing Library for Medical Applications

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1 Introduction

The display and manipulation of medical images is becoming a very important part of PACS (Picture Archiving and Communication Systems) and HIS (Hospital Information Systems) [6]. The access and manipulation of medical images in digital form require different functionalities. The most common are visualization, image file transfer, storage in a database etc. These functionalities are most useful when they are unified. Different unification models exist but the overall concept is very simple. There must be the ability to display, enhance and process medical images in a multi-purpose workstation, to intergrate different image and medical modalities in a consistent way and to communicate and exchange information between different systems, possibly located at different places.

Towards this direction the design and the implementation of a Unified Medical Workstation (UMWS) was decided, as part of the TELEMED project. A very important low-level part of the UMWS is MIPL. MIPL (standing for Medical Image Processing Library) is an image processing library for medical images. MIPL is essential for supporting all kinds of image manipulation required by the UMWS. MIPL is part of the Display Tools (DSP), which, in turn, are part of the Unified Presentation Tools (UPT). These are used to implement the Unified Medical Workstation Tools (UMWST), which are necessary to support any application written for the Unified Medical Workstation (UMWS). Although MIPL will be used for medical image processing, it is designed to be used as a general-purpose image processing library also.

Other programs for manipulation of medical images are EXPLORER [2], OSIRIS [3] and LiteBox [4].

2 General overview

2.1 Features

MIPL [5] is designed to handle images that are produced by different modalities. These images are very different with respect to some parameters that characterize

certain attributes of them. Examples of such parameters are image size, image depth, type of image data etc.

MIPL is able to handle images of very different sizes. In fact there is no restriction in the size of an image that MIPL can handle. The only limit that applies to the size of an image is the memory available in the target workstation that executes some function of MIPL.

Apart from different sizes, images can have different depth. By depth we mean the number of bits needed to represent the gray scale level of one pixel in the image. Bigger depths means that there are more gray scale level for the visualization of the image and thus a physician can have better understanding of this image. MIPL can handle images with any depth, as long as this is less or equal to the number of bits used to represent the `long int` type in the target workstation.

Additionally, MIPL supports different types of image data. The supported types are byte, word and double word either signed or unsigned and single or double precision float. That is, MIPL will accept and manipulate any image that has its data represented as a sequence of numbers of any of the above types.

MIPL can handle images of higher dimensions (3-D and 4-D). 3-D images can be thought of as either true representations of 3-D objects (a tomography) or as time sequences of a 2-D objects. 4-D images can be thought of as time sequences of 3-D objects. MIPL supports any image processing operation that can be defined in these higher dimensions (there is a certain difficulty in defining or extending the meaning of some operations in more than two dimensions).

At last, MIPL can handle parts of images, the so-called ROIs (Regions Of Interest). ROI handling is very useful when only a small part of the image is of interest. In such a case image processing can be done in that area only, saving a considerable amount of time.

2.2 Advantages

MIPL is implemented in the ANSI-C programming language. It does not depend on any specific attribute of the computer and it does not require any special-purpose hardware. So it is hardware independent and can be ported to any machine. That is very important because MIPL will be used for medical applications and currently the computers used for medical applications are of very different type even within the same hospital.

MIPL has an object-oriented design. Apart from the ease of implementation that this design gave us, it also hides the details of the implementation from the user of the library. This way one does not have any access to the internals of the MIPL, cannot alter any attribute and cannot use "quick and dirty" programming. Thus, a good numbers of serious errors may be avoided.

The above is not the only prevention MIPL takes against errors. It, also, incorporates an error checking mechanism. MIPL checks all parameters against

meaningless, erroneous, or impossible values. When a parameter is of a higher level type all the attributes of this parameter are checked to make sure that their values are compatible with each other. MIPL, also, checks for errors that might occur during the execution of one of its functions. When an error is encountered MIPL identifies it and informs the higher level (the application using the library) about the existence and the type of the error. This is done by returning an error code and setting an internal variable to an appropriate value.

2.3 Disadvantages

Image processing is a very time-consuming task and usually it needs the assistance of special hardware. On the other hand MIPL is hardware independent and cannot rely on any special hardware to speed operations up. Thus MIPL is not very fast (Although it seems to be fast enough when executing in a workstation, this may not be the case when used in a personal computer). In order MIPL to be as fast as possible, the code of MIPL is optimized to achieve full speed.

Also, MIPL seems to be large in size. This is a consequence of the ability of MIPL to handle images with very different types of image data and the speed optimization. Similar portions of code had to be repeated for every one of the supported data types. This is not much of a problem if one considers the amount of memory that a typical workstation has and the fact that a typical medical application may use only a part of MIPL and not the whole library.

A good way to improve the speed and reduce the size of the library is to use special-purpose hardware. The library will not be any more hardware independent but may still be portable if one chooses to use hardware that is widely available for the most commonly used personal computers and workstations (UNIX machines).

3 Structure of MIPL

3.1 Overall Design

The internal design of MIPL is object-oriented. This means that everything used or manipulated by MIPL must be an object. This design greatly simplifies the implementation of the library, reduces the errors during implementation and makes debugging much faster and easier. This is very important, if one considers what a task is to implement a fully-featured image processing library.

Another great benefit of the object-oriented design is data hiding. All implementation details are hidden from the user of MIPL (the application in the higher level) and the basic object manipulation is obtained through the use of some primitive functions (methods) of MIPL. These are not image processing functions but they are provided by MIPL in order for anyone to be able to handle the objects supported by MIPL.

The effect of the particular design is that the user of MIPL (application programmer) is somehow "forced" to use good programming techniques. This prevents him from making several minor or major errors and, thus, speeding up his job and saving him a greatdeal of effort.

The objects supported by the library are image, histogram, look-up table and region of interest. Each object is manipulated by several functions provided by the library.

The implementation of the library had to be done in the ANSI-C programming language, which is not an object-oriented one. The implementors of the library used several techniques to avoid the limitations and achieve a more object-oriented implementation.

The primary data types used in conjunction with MIPL are :

- Rc (return code)
- Image
- Histogram
- Lut (look-up table)
- Roi (region of interest) — In two dimensions only.

They are defined by common ANCI-C definitions

In order to achieve data hiding the user of MIPL is not allowed to see these definitions. The definitions that he sees look like

```
typedef void *Image;

typedef void *Histogram;

typedef void *Lut;
```

which means that the above types are pointers to something but no clue is given to what this "something" might be.

This way he cannot see the details of the impementation (A basic idea behind the object-oriented design).

The functions provided by MIPL are covering all the topics in the medical image processing field and they are, generally, not depending on one another. This was a great convinience for the implementors of MIPL since every new image processing function that was added to the library could be tested and debugged separately.

The independence of the library functions, also, has another advantage. When one wishes to use only a limited number of the library functions, only these functions will be linked and so the resulting program will not be large in size.

The functions of MIPL are organized in three levels. This decision was made by the designers of MIPL because for the application of some operators a certain preprocessing of the images must take place. So there exist functions for both the preprocessing and the final processing.

In the first or low level belong the functions that perform the preprocessing. In the second or medium level belong the functions that combine the results of the preprocessing to obtain the fully processed image. In the third or high level belong the functions that are responsible for calling the low level functions to do the preprocessing and the medium level functions to do the combination of the intermediate results.

All the functions in every of the three levels are accessible from the potential user. This way one can choose to, only, preprocess an image (if one is interest in the intermediate results) or to combine previously preprocessed images (without preprocessing them again).

3.2 Modules of MIPL

Image processing operators are categorized according to their function and domain of application [1]. This categorization is heavily used in the literature. The designers of MIPL used this fact and decided to organize MIPL in a modular way, according to the previously mentioned categorization.

MIPL includes modules for the following topics :

- Mathematical operations between a number and an image.
- Mathematical operations between two images.
- Logical operations between two images.
- Image transformations (FFT, inverse FFT etc.).
- Spatial filter operations.
- Band-pass and band-reject filtering (frequency domain).
- Histogram operations.
- Contrast and image enhancement.
- Edge detection.
- Zooming and replication.
- Image type conversion.

The above modules does not include the basic object manipulation functions. (These functions are not image processing functions but they are used to support primitive object manipulations)

3.3 Error handling

MIPL has built in an error checking mechanism. This mechanism is a very important part of MIPL. The designers of MIPL paid a lot of attention when designing this mechanism and made it compact and robust. The error checking mechanism checks against errors made by the user of MIPL (probably an application), faulty parameters and erroneous conditions during the application of an image processing operator.

Before going on and describing the error checking mechanism, we must make clear what is an error for MIPL. For MIPL there are two kinds of abnormal situations. The first one is when MIPL cannot continue the application of a function, probably due to some invalid parameters and subsequently cannot produce a result. The other abnormal situation is when MIPL has finished its processing, produced a result and detected some problem, but it is possible for the application using the MIPL to ignore the error and continue.

An example of such a situation is the overflow problem. This occurs when there is not enough memory allocated for the image resulting from an operation of MIPL. In this case MIPL discards some bits of some pixels producing an image with some pixels altered and reports the abnormal situation. From now on the application can either continue, ignoring the fact of some pixels being damaged, or stop and report the error to the user.

MIPL can detect both of the above situations and will report them. When a function of MIPL terminates normally it returns a code of `MIPL_OK`. This means that everything went fine. If an error is detected by the error checking mechanism then MIPL will return either `MIPL_ERROR` or `MIPL_WARNING`. The first code means that the error was fatal for MIPL and no output is produced. The second code means that MIPL did its best and produced some output but with possible loss of information. The application using the MIPL has now the responsibility of continuing.

When MIPL reports an erroneous situation, it is possible for the application to figure out what went wrong by calling the function `mipl_get_error()`. This function will return a code that shows what exactly what the problem was. After that the application can take some actions to correct the situation and resume execution.

4 Conclusions and further work

In this work we have described MIPL, one medical image processing library. MIPL is the first approach in the area of object-oriented programming for medical image processing. The overall design of MIPL is sophisticated and up to now the library is hardware independent.

The next step will be to use special hardware to achieve more speed and efficiency. In order not to loose the portability we shall choose hardware that

is widely available for every personal computer and workstation. Another step will be to use parallel hardware image processors. This way when one wishes more speed he must only add some more hardware modules.

Finally we have started the development of a user friendly interface that uses MIPL under X-Windows.

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PTRADS – A Database for Percutaneous Transluminal Renal Angioplasty

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ABSTRACT

The development of a relational database to store and analyze data collected during the treatment and follow-up of patients undergoing percutaneous transluminal renal angioplasty is described. The ease and speed of ad hoc analysis allowed by the database are its greatest benefits and have proven essential in deriving important new clinical information to aid in patient management. The complexity of the logical structure of the database necessitated by the intricate and inter-related data collected has proven its greatest limitation.

INTRODUCTION

Renovascular hypertension (RVH) due to renal artery stenosis is the most common potentially curable cause of systemic arterial hypertension¹. Percutaneous transluminal renal angioplasty (PTRA) is considered the treatment of choice for the disease². The success of PTRA depends largely on the underlying cause and location of the stenotic lesion. Given the potential morbidity and mortality associated with the procedure and the availability of alternative medical and surgical therapies, prospective and retrospective analyses to identify patient subgroups most likely to benefit from PTRA are essential to optimize patient management. However, the large quantity of complex and interrelated clinical, biochemical, pharmacologic, and radiologic data collected during the study of these patients renders traditional manual data analysis frustrating, cumbersome, and time-consuming.

The relational data model was developed by Dr. Edgar F. Codd in 1970. In this model data are organized into multiple tables (relations) linked via common fields (keys). Its power and simplicity have made it the model of choice of a number of commercially available micro-computer-based database management systems (DBMS), including

R:BASE for DOS, dBASE, and Paradox. These commercial products supply the programming environment and tools with which customized database applications may be designed and implemented.

The limitations of the traditional manual method of data analysis and the ready applicability of commercial DBMS's prompted us to develop a customized relational database to facilitate the analysis of patients undergoing PTRA at our institution. This paper will discuss the development and use of the Percutaneous Transluminal Renal Angioplasty Data System (PTRADS).

METHODS

Emory University Hospital serves as a referral center for patients with RVH who are to undergo PTRA. Data from these patients are routinely abstracted from the procedure report, inpatient and outpatient medical records, and correspondence with referring physicians and entered onto coded data summary forms. Manual analysis from these forms generates results for publication.

PTRADS was designed as a single-user relational database to facilitate the input, analysis, and output of clinical research data collected from patients undergoing PTRA. Goals in its development included the ability to:

1. Enter and store the diverse data acquired treating and following patients undergoing PTRA;
2. Check these data for consistency and accuracy;
3. Perform ad hoc data analysis;
4. Allow easy transition from existing data summary forms;
5. Use a commercial DBMS running under the Microsoft Disk Operating System (MS-DOS) on an IBM-compatible micro-computer.

PTRADS was developed using R:BASE for DOS version 3.1 running under MS-DOS version 3.3. While improved performance is evident on more powerful microcomputers, the database has been used successfully on a monochrome 4.77 MHz 8088-based machine with 640 kilobytes (kb) of random access memory and a 20 megabyte hard disk.

The design and development of relational databases have been well described by other authors³⁻⁸. Basic steps in the development of PTRADS included:

1. Requirements Analysis: Identification of problems with the current data collection and analysis system and requirements and goals of the new database;
2. Data Analysis: Analysis of existing data collection forms to identify important data to be managed and the relationships between these data;
3. Normalization: Organization of the data into multiple relations with primary keys;
4. Implementation: Implementation of the logical structure of the database from the normalized data;
5. Application Design: Design of data entry and report forms, validation rules, menus, subroutines, etc;
6. Refinement: Successive iterations of steps 1-5 to create the final database implementation.

Prior to analysis, data from existing coded data summary forms were manually entered into PTRADS and checked for consistency and accuracy.

RESULTS

Data from 321 patients who have undergone 376 PTAs over the past 12 years are stored and available for analysis. These data are contained in three data files with a combined size of approximately 925 kb.

The logical structure of the database consists of 124 fields organized within 14 normalized relations. Eight relations store actual clinical data and results and include:

1. Patient: Administrative and demographic data, calculated and summary results;
2. PtDaily: Clinical follow-up data and date of collection;

3. PtDx: Diagnoses carried by an individual patient;
4. PtRenin: Laboratory results from renal vein renin sampling;
5. PtRnSmpl: Calculated and summary results of renal vein renin sampling;
6. Procedur: Overall procedural data;
7. ProcVesl: Vessels, stenotic lesions identified, and catheters used;
8. ProcCmpl: Actual complications of a procedure.

The remaining six relations serve as lookup tables to facilitate data entry and presentation, storing lists of possible: lesion locations (LsnLocat), affected arteries (Vessel), lesion etiologies (LsnEtiol), patient diagnoses (Diagnos), procedural complications (Complic), and sampled veins (RninSmpl).

Five data entry/retrieval forms are used. Four mimic the existing paper data summary forms to minimize errors by keypunch operators accustomed to those forms while the fifth form provides a single screen summary of pertinent clinical data related to a given patient retrieved from multiple relations. Output demands placed upon the database have not been as critical as input demands, consisting primarily of follow-up letters to referring physicians. These letters are addressed and personalized through the mail-merge capability of the database, which simplifies correspondence and improves long-term data collection.

PTRADS greatly facilitates data analysis and has proven essential in deriving results for two retrospective investigations. The first of these indicates that patients with ostial renal artery stenosis obtain greater benefit from the procedure than previously described and may profit from its expanded role in their management⁹. The second compares the results of pre-procedural renal vein renin sampling and post-procedural patient outcomes to suggest a limited value of renal vein renin sampling in predicting who will benefit from PTR¹⁰.

DISCUSSION

PTRADS provides five major advantages compared to our prior system of data storage and analysis. First, prompts, defaults, lookup tables, and validation rules improve the speed, ease, and accuracy of data entry. Second, predefined and user-definable functions, formulae, and subroutines automatically manipulate entered data to obviate possible user mathematical errors. Third, the database allows rapid and easy ad hoc analysis of the stored data. Fourth, formatting, sorting, and conditional retrieval of the stored data enhance transfer to magnetic data files or output to paper copy. Finally, data storage on removable magnetic media improves data security and minimizes storage space required.

Three major problems limit the utility of this database. First, the intricate and interrelated data collected necessitate a complex logical data structure. Only the program's developer has been able to successfully negotiate this data structure to perform the analyses desired. Second, the simple statistical functions provided within the DBMS are not powerful enough for the complex analyses required. This has required some data output to paper copy or transfer into a dedicated statistical program for further analysis. Third, limited time available for database maintenance and lack of end-user training hinder database acceptance and use.

To overcome the limitations described we are considering collection of a simplified subset of data and use of the simpler flat file data model, direct exportation of existing data into a dedicated statistical program for more sophisticated analysis, and designation of a database administrator and increased end-user training to improve database utility.

CONCLUSIONS

1. Commercial microcomputer-based relational database management systems can be successfully customized into productive clinical research databases.
2. These databases can greatly enhance data entry, maintenance, analysis, and output as compared to traditional manual methods.

3. To facilitate database use and maintenance, the simplest design compatible with the data to be managed and the analyses to be performed should be used.
4. Database management systems do not serve as substitutes for dedicated statistical programs for more than simple statistical analyses.
5. A designated database administrator and end-user training will increase the utility of the database.

ACKNOWLEDGEMENTS

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DECrad/CHOP/IDX/TDS/MAC: They Came, We Saw, We Interfaced

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The Radiologist's Perspective:

In 1989, the need for a Radiology Information System (RIS) was evaluated and endorsed as a major goal of The Children's Hospital of Philadelphia (CHOP). Vendor selection and negotiations continued over a period of two years until a contract was signed by the hospital and IDX, Corp. to purchase and install the DECrads system. The planning, implementation, and installation processes have continued over the past year and involved teams from IDX, and CHOP Radiology and Data Processing departments. The most important, and ultimately the most expensive and time consuming issue to be resolved was establishing an interface for the new RIS with the pre-existing hospital information system, i.e., TDS. Although an interface had been developed elsewhere and was available, the proposed cost was prohibitive. Therefore, we decided to develop our own interface (with the help of outside consultation) which further delayed the start-up date. An interface with a local network of Macintosh PC's through the VAX based hospital network is planned, as well as an interface with an IDX out-patient registration system.

Before DECrads could be installed, several decisions had to be made regarding departmental policy and procedure, especially concerning the film library (file room). We analyzed the existing manual system and correlated the necessary elements with similar automated DECrads functions. Conversion from a unique x-ray number to the patient's master medical record number meant preparing and purging the existing files and making room for the newly numbered files within the limited existing space. An outside consulting firm was hired to accomplish the actual physical conversion of the files and to locate, retrieve and file as many outstanding film jackets as possible. During this process, approximately 30,000 master jackets were converted prior to the DECrads start-up. Changes in the policy of borrowing films were instituted prior to the "clean-up," but were limited by the existing manual sign-out system. In addition, a review of the hospital master patient index revealed an unacceptable number of duplicates and errors which needed correction prior to DECrads.

A decision to bar-code hospital employee identification badges was sponsored by the DECrads task force committee in order to facilitate film jacket borrowing and retrieval. This, in turn, required the approval of the hospital administration as well as the hospital security department which issues the identification badges. It seemed as if nothing could be decided or instituted that did not impact on other departments, or which required specific approval or funding by the hospital administration, or required

outside consultants or manpower to accomplish. All of these tasks slowed down the process and provided moments of personal and group frustration in trying to get the job done in a timely fashion.

Although it was recommended that the Radiology department hire a DECrad manager, it was decided to expand the role of the department administrator (who had considerable computer expertise) and the assistant administrator (who was thoroughly familiar with the old manual "system") and share the responsibility with a systems manager assigned to the project by the Data Processing department which is responsible for all hospital computer systems. At times, differences in perspective and priority had to be settled before progress could be achieved. Most of these difficulties stemmed from the decision not to install DECrad as a stand-alone system, but rather, to incorporate it into the existing hospital computer milieu.

The long wait is finally coming to end. Despite the general consensus that an RIS is long overdue and greatly needed, the technical, logistic, and human obstacles to final DECrad start-up have prolonged the process well beyond anyone's reasonable expectations. As the saying goes, "Nothing is as easy as it looks; everything takes longer (and is more costly) than you expect; and if anything can go wrong - it will at the worst possible moment."

The Radiology Administrator's perspective:

In bringing the DECrad system from theory to life, the administrator was required to assume the roles of team leader, diplomat, and benign dictator as the situation and phase of the project demanded. As the project got under way, the Team Leader organized the team consisting of key staff from Radiology, Data Processing, and Administration. Regular meetings were held to identify the various tasks and develop a time line for project completion. Initial concerns centered on technical matters. The DECrad/TDS interface proved to be a complicated issue which took seven months and three postponement dates to resolve.

The interface delay caused secondary delays. Since the operational details of the interface were still undecided, it was not possible to write the job-specific user procedures or to test the system documentation. These delays negatively affected the group's morale and required the Diplomat to intervene.

Initially, delays in the project timetable were accepted with understanding and compassion since the technical issues relating to the interface were viewed as inevitable. However, once the interface became operational, understanding and compassion quickly waned. This resulted in additional meetings with the administration and physician leaders where the challenge was to concisely identify the issues and report progress without laying blame on individuals or departments. When a third delay became inevitable, a consultant in system implementation was retained. At this point the benign Dictator emerged.

The consultant reviewed the project and quickly declared that it was "90% complete." However, the last 10% would require firm, action-oriented leadership.

Enter the Dictator. Team meetings increased in frequency and fervor. Team members were assigned activities and were encouraged and empowered to achieve their goals. Meetings with departmental staff for procedure development and training stepped up. A phased start-up was planned and implemented. An aggressive timetable was established which required other involved departments to view the DECrad project as critical and act on requests without question or complaint. The dictatorial style, although not appreciated by all, unified the team and achieved the desired results, which in turn, further encouraged the team and picked up morale.

In retrospect, successful implementation required four ingredients: 1) a team of capable and hard working individuals, 2) strict attention to technical and hardware issues, 3) utilization of general staff in analyzing work flow and writing up new procedures, and 4) an openness to recognize the need and obtain outside help if and when the project stalled. Although the project as a whole truly represents a group effort, it was important that one individual be empowered and held responsible for its ultimate success.

The System Manager's perspective:

DECrad/TDS Interface:

DECrad represents the latest addition to the myriad of specialized departmental systems at CHOP. While the ideal goal might be a set of seamlessly integrated software modules which effectively address the diverse informational needs of all concerned, the reality of the greater functionality found in independent departmental systems favors an *interfaced* approach over one of *integration*. Because DECrad is designed as an independent, "stand alone" system, several functions were found to be redundant with respect to portions of the existing hospital system. These included patient registration, billing, and order entry functions. In order to continue to use and ultimately expand the hospital information system (TDS), it was vital to create a two way, real time interface between TDS and DECrad.

Coinciding with the implementation of DECrad was the installation of a new ADT system (IDX) which operates on the same hardware platform as DECrad, i.e., a VAX cluster. A separate interface was designed to ensure that a core of demographic data would pass from this new front end to TDS. Thus, the main interface for each departmental system could be with TDS.

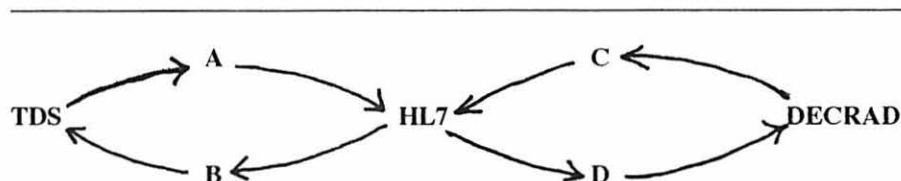
Among the difficulties to be overcome, were the constraints imposed by the proprietary concerns of both TDS Healthcare Systems and IDX Corporation that precluded any modification of source code. Nevertheless, a solution was found which, while respecting these concerns, provided a transparent, two-way, real time interface using the Health Level Seven (HL7) standard.

The task of connecting any two computer systems together so that they can communicate predictably is always complicated by the independent database design of each system. The databases are not only physically different, but they are logically independent. Entities defined in one system may or may not occur in the other. In the health care field, however, a certain core of abstract entities has been recognized.

Characterized as both objects (patients, orders, etc.) and events (admissions, cancellations, discharges, etc.) the HL7 Standard endeavors to provide a common schema for the import and export of this information among all health care applications.

Role of a Data Bridge:

Central to the implementation of the TDS/DECrad interface was the use of a PC bridge between the two systems. 2 PC's are used: one for inbound, the other for outbound messages. Conceptually, the two units function as a single machine. The bridge, built upon the architecture of HL7 abstract message types, is at the confluence of four data streams as shown below:



These four data flows were isolated and developed separately:

- *TDS printstring to HL7 format (A)
- *HL7 format to TDS keyboard emulation (B)
- *DECrad output to HL7 format (C)
- *HL7 format to DECrads input (D)

The common framework of HL7 at the bridge insured the compatibility of the two independent programs. For example, an order initiated in TDS can be passed to DECrads via the composed relation (AD). The bridge accepts a data stream from TDS in a format usually reserved for a printer (A). After being parsed and reformatted into an HL7 message in the environment of the bridge, the outbound messages are sent serially to DECrads (D). Conversely, inbound messages from DECrads are received in the HL7 format. Decomposed in the environment of the bridge into data objects recognizable to TDS, specialized scripts emulate a user at a keyboard effecting the necessary actions in TDS.

In this way a wide variety of common standard functions are implemented by this real-time, two way interface. All of this is accomplished without changing the internal architecture or format of either system. The potential versatility of this interface concept makes it extremely attractive as other software providers embrace the HL7 standard. Thus, the transparent **interface** of specialized departmental information systems may be much better than a theoretical comprehensive, gigantic mega-system that tries to do it all.

The Hospital Administrator's viewpoint:

The successful implementation of a departmental computer information system relies on the project team's comfort level with the proposed "go live" date. Maintaining this comfort level requires the commitment and effort from team members as well as organizational support in completing assigned tasks on time. Team harmony and comfort with the "go live" date can deteriorate if critical management issues are not considered during implementation of the project.

Establish **ownership** of the system and implementation process.

This is where many interdepartmental project teams run into trouble. The issue of who owns the system and who is driving the process must be established from the outset. Failure to do so will impede the team's ability to complete the final steps. Someone must be empowered and accountable for the final direction and countdown.

Recognize team **conflict** and intervene with **constructive** strategies to achieve resolution.

Unresolved conflicts will only bring on endless finger-pointing. When necessary, jump in and help the team resolve differences with effective strategies.

Expectations for successful project implementation should be **deferred** to members of the **team**.

In defining the expectations for success, the team will find it difficult to ignore the senior leadership. However, senior leadership must recognize that a team which plays to outside influences can impede its ability to focus on the true operational and technical components which affect the project's success.

The team must identify the **critical decision points** leading to the realization of a firm "go live" date.

Do not let the team wait until the last minute to develop critical decision points. The team must meet regularly to review and evaluate the major components affecting the "go live" readiness and understand the key issues driving the final countdown. These will include, but are not limited to the following:

- *System functionality and interface
- *Conversion planning
- *Operational procedures affected by the RIS
- *Staff readiness and training
- *Vendor support for final implementation
- *Communication to all affected by the RIS

Finally, do not hesitate to review and analyze the entire process after final installation has been achieved. Try to identify significant pitfalls as well as necessary improvements. Discuss how the team might have done things differently now that they have gone through the DECrad experience. After all, another departmental information system is just around the corner.

SESSION 15

**Picture Archive
and Communication Systems**

Chair: Norman D. LaFrance

Clinical Examples of Image Compression Using a Full Frame 2-Dimensional Discrete Cosine Transform

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Compression of medical images is a technique to reduce the amount of storage required to archive images and to reduce the transfer time required to transfer images between sites and an archive. The goal is to be able to compress the original image as much as possible without loss of diagnostic information. This is a different criteria than allowing no loss of information. How much compression is acceptable is subject to discussion. Rapid and efficient implementations of the compression process are required and have been implemented in hardware. The hardware implementations have the speed advantage but lack some of the flexibility that software implementations offer.

The amount of compression that may be achieved without information loss, i.e. lossless compression, is limited to between 3:1 to 4:1.

The amount of compression that may occur with information loss, i.e. lossy compression, may range from 1:1 to 500:1. There are many lossy compression methods. One common method is the full frame discrete cosine transform (FFDCT). By varying the quantization levels in the coding of the transformed image; different compression ratios may be achieved. We utilized an implementation of the full frame discrete cosine transform that was developed by RunTime Technologies. A combination of hardware and software was implemented on an IBM AT type bus card that contains a Motorola 96002 chip. Additional image processing algorithms have been implemented on the board by changes in the programming software. This board is able to store an entire 2,048 by 2,048 x 12 bit image in memory and process it at 50 MIPS. Compressing an image takes place internally without external transfers after the image is initially loaded into the board.

Initial experiments with computer generated phantom images were not successful. The distribution of grey levels in simple phantom images did not match clinical images. Compression/decompression artifacts and compression levels did not match clinical cases. Two sources of clinical images were then selected. Digitized plain film images that are approximately 2,048 X 2,048 X 12 bits and computed radiography images that are approximately 2,048 X 2,048 X 10 bits were chosen.

We did not look at two types of clinical images that are known to be very difficult, i.e. mammograms and small non-displaced fractures. These two sets of images are difficult even on plain film and therefore also would be expected to be difficult on digitized versions of the plain film. We also did not look at images that were lower in resolution than 1,024 by 1,024. This included CT, MR, and ultrasound images. High contrast lower resolution images or 8 bit video capture images were expected to perform differently than 2,048 X 2,048 images of 10 or 12 bits.

Within the area of digitized plain film we looked at chest radiographs which had a pneumothorax or lung nodules which are subtle and would give an indication of the performance of different levels of compression. The plain film radiograph were digitized on a film digitizer at 2,048 by 2,048 resolution, stored on magnetic tape and on magnetic disk to be available for further processing.

Images from computed radiography included a variety of different types of images. We selected cases with and without subtle pathology. The computed radiography images were all produced on a Siemens Digiscan system and stored in a packed format on an optical disk. The archived images stored on optical disk were unpacked and transferred to magnetic disk where they were available for further processing.

Each digital image was approximately 8 megabytes. It took approximately 65 seconds to load an image to be processed into the RunTime Technologies Board internal memory. The compression process takes between 40-80 seconds and the compressed image is then transferred back to the network which took from 1-11 seconds. A series of different compression parameters were used to produce different levels of compression. Typically 11 compressed/decompressed images with different compression levels were produced from one original image. The decompressed images were transferred along with the original digital version of the image to a Kodak Laser film printer and then printed with identical printing parameters. In this manner 12 images were produced. We also produced subtracted images which were the compressed/decompressed image subtracted from the original in a point by point manner. In these subtracted images the difference between the original and compressed images at each point was then evident.

Radiologists then examined the images and selected the last image where the diagnostic information was still readily identifiable and there did not appear to be loss of diagnostic information.

An example of the compression ratios produced from one original image is the following: 4:1, 5:1, 7:1, 15:1, 33:1, 72:1, 140:1, 228:1, 323:1, 405:1, 451:1. Our results show that levels of compression are very image dependent. Some of the

factors that influence the amount of compression that is acceptable without diagnostic information loss are:

1. Physical size of the image.
2,048 X 2,048 images compress better than 512 X 512 images.
2. Number of bits in each pixel.
10 bit images compress better than 12 bit ones.
3. Amount of contrast in the image.
Low contrast images compress better than high contrast images.

The clinical images we examined demonstrated that images may be compressed 40:1 without loss of diagnostic information. This results in a digital data file that is 200,000 bytes in size instead of the original 8,000,000 in size. There is also a corresponding reduction in transfer time of the compressed version of the image.

Gross abnormalities were visible even at higher compression levels. There was obvious loss of information in the compressed/decompressed image but the gross abnormality was still visible.

At approximately 100:1, the subtracted image contained evidence of the structure of the original image. The outline of the bones and other edges was visible in the subtracted image. Information was being lost.

Images that had large areas of blocked out image, resulting in large white areas demonstrated ringing throughout the image caused by the high frequencies of the black/white edges. This noise was spread throughout the image. Lower compression ratio images demonstrated less noise at all points in the image. Any other white parts of the images such as position markers and ID blocks also resulted in noise distributed throughout the compressed/decompressed image. This also indicates that images that normally have very high contrast areas such as bone pins, catheters, guide wires, staples, buckshot, bullets, buttons, jewelry, and dental work all will have some noise spread throughout the compressed/decompressed image. Preprocessing to reduce or remove these areas may reduce the occurrence of noise artifacts in the resulting image.

To discover the effect of repeated compression/decompression on an image. A computed radiography case containing a gallstone was selected and 100 repeated compression/decompressions were performed. The ringing and noise artifacts built up in the image after each compression/decompression until they were distributed throughout the image. The conclusion was that only one compression should be made and the compressed version of the image retained both for archival and transfer.

Determination of the number of pixels and amount of change in each pixel in the compressed/decompressed image demonstrates that many pixels are changed but by smaller amounts in the lower compression level images. A very high compression levels many of the pixels in the image had changed by very large amounts.

Conclusions:

Subtle clinical conditions are visible even on 40:1 compressed/decompressed images. More gross abnormalities are visible even at higher compression levels. Rapid compression/decompression of medical images is feasible. A combination hardware/software implementation of the full frame discrete cosine transform is one solution. Creation of display and archival stations with built in compression/decompression capability could reduce storage and transfer times. This could be a single board inserted in the digitizer, display, archive, CT, MR, or computed radiography unit. Selection of the levels of compression acceptable to each user could be user and examination specific. For example a unit connected to an Emergency Room and used for quick overviews might utilize higher levels of compression while consultation and diagnostic workstations may select lower compress levels.

Filmless Capability in Nuclear Medicine

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Abstract

The Department of Nuclear Medicine, North Carolina Baptist Hospital/Bowman Gray School of Medicine, is networked so that all images are computer acquired and viewable from a central reading station. The department has five ADAC Pegasys processing/display stations, with acquisition from four standard gamma cameras, one SPECT camera and one dual-head whole-body scanner. The network also includes a link to a TRIONIX Triad SPECT Camera. A MedImages DELTAMANAGERtm located in the reading area is also on the network. The Nuclear Medicine LAN is networked to the P.E.T facility and imaging research LAN via a hospital-wide fiber-optic backbone. All images are converted to the correct format for display. All static images are also given ACR-NEMA headers for transfer to our PACS system.

Introduction

Nuclear medicine is considered the easiest area of medical imaging to convert to filmless technology. Two major reasons for this are 1) the small image formats required for nuclear medicine images and 2) most nuclear medicine physicians are computer literate, since larger nuclear medicine departments have been computer dependent to process and help in analysis of data for the past fifteen years or so. Regardless of these factors, nuclear medicine departments have largely been ignored by the PACS vendors and by ACR-NEMA versions 1 and 2. Thus far, the only way for nuclear medicine departments to become filmless has been with a local nuclear medicine PACS.

Many departments over the years have reported being digital, but only one, Beth Israel Hospital, Boston, MA, has reported being filmless.¹⁻⁴

The following are reasons for moving toward a filmless department. Their order of importance varies from site to site.

- a. Remote acquisition and viewing
- b. Digital display of images
- c. Digital image archiving
- d. Long-term cost savings¹

The following are important factors to consider. Again, the order of importance may vary from site to site.

- a. *Start-up cost.* Although long-term cost savings might be realized by use of a digital department, the cost of purchasing the equipment, installation, and connecting all the necessary components may be prohibitive.
- b. *Speed.* Speed is always a consideration. A digital system will not be accepted if it slows down the normal work routine.
- c. *Ease of use.* The computers must be easy for the user to work with. If the digital system is to replace film (with which everyone is familiar), the computer application must be easy to learn and must provide improvement in service, i.e., more speed and/or better diagnosis than film.
- d. *Reliability (long-term storage).* There must be sufficient computer reliability to keep the department functioning. This need not mean redundancy in every item but may mean redundancy in the functions that are most critical. For example, if there is no film and the physician needs to compare with a previous study, the necessary reliability of the long-term storage device, where these images are to be found, may be achieved with sufficient redundancy.
- e. *Connectivity.* Most nuclear medicine departments are composed of an assortment of equipment of varying ages and from different manufacturers. In order to become a digital department it is necessary that all of these items be connected in a fashion that will allow images to be sent to the physician for reading. These images must be formatted in such a way that the physician's reading station can display and manipulate them.
- f. *Future purchases.* Long-term plans for the department should always be kept in mind. Future purchases should be compatible with the digital system within the department. Ideally this can be accomplished by choosing "industry standard" workstations and operating systems. If possible, the position of "having" to purchase from a certain vendor should be avoided.

Implementation

At present the Department of Nuclear Medicine, North Carolina Baptist Hospital/Bowman Gray School of Medicine, is networked so all images can be computer acquired. The department has five ADAC Pegasys computers. The

Pegasys computer is based on a Sun SPARC-2tm platform. Each of the Pegasys computers has a 669-Mbyte disk drive, 40 Mbytes of memory (16 Mbytes RAM and 24 Mbytes image memory). An important feature of the Pegasys computer is an ADAC priority image display board, which improves the display capabilities. The Pegasys can display images (static or cine) in multiple windows with different color scales in each window and differing cine rates.

The display board controls a 1152 x 900 resolution 16-inch color monitor. Four of the Pegasys computers are capable of acquisition and processing; the fifth is processing only. Of the four acquisition-capable units, two are interfaced to two standard gamma cameras each, one is interfaced to our standard SPECT system, and one is interfaced to acquire both detectors from our whole-body scanner. The processing-only Pegasys is centrally located and is used for production of film and also has the archive device (optical disk). Also in the network is a MedImages DELTAMANAGERtm for display purposes (Figure 1).

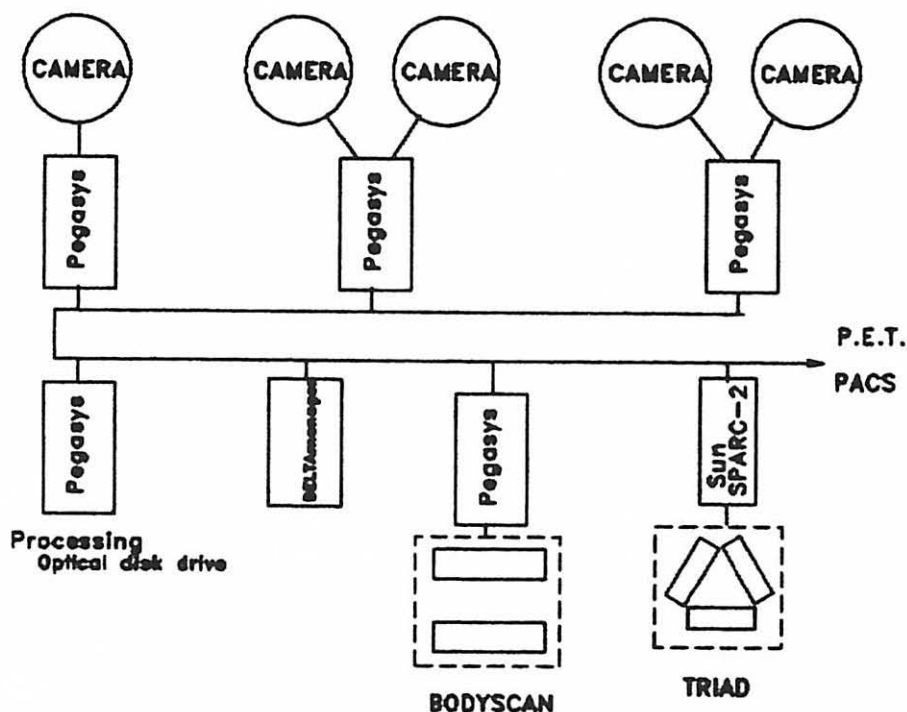


Figure 1. A schematic diagram of the Nuclear Medicine Department showing the workstations and the networking.

The other imaging device in the department is a TRIONIX Triad, triple-headed SPECT. The Triad has its own Sun SPARC-2tm. At the present time both vendors are using UNIXtm as the operating system and all the programs are written using the SunView Window System. Though the ADAC Clinical Applications Package and the TRIONIX clinical software differ, the commonality of UNIXtm and SunView facilitates going from one set of software to the other.

The use of the same hardware platform and operating systems allows a much easier interface than do differing systems. The Triad is in the same network as the Pegasys systems. Since UNIX is "talking" to UNIX, file transfers are easy between the ADAC system and the TRIONIX system. At first it was thought that programs to translate the header information between the systems would have to be written in house, but both ADAC and TRIONIX are now supporting the Interfile protocol for image exchange; therefore, images can be readily transferred from one system to the other and displayed. At the current time Interfile does not support headers for list mode studies, curves, regions of interest and screen saves.⁵ For the short term it is felt that the Interfile transfers will be sufficient. If in the future it is decided that the other studies are needed, we will write our own header conversion routines if newer versions of Interfile have not addressed the issue.

The MedImages DELTAMANAGER was purchased with an ADAC interface. The conversion from TRIONIX headers to ADAC headers via Interfile allows the display of the TRIONIX images on the DELTAMANAGER without having a TRIONIX interface on the DELTAMANAGER.

The P.E.T. facility is located several hundred feet from the current nuclear medicine area. The CTI/Siemens scanner uses Sun SPARC-2tm workstations for control of the scanner, processing and display of images. These workstations are also using UNIX for the operating system and the SunView window system. These workstations are on a LAN with the medical image research engineers. The LAN in nuclear medicine and the LAN the P.E.T. facility is on are connected by a hospital-wide fiber-optic backbone with a bridge at each end to help control overall traffic. Header conversions are made so that nuclear medicine images are viewable on the Sun workstations in the P.E.T. facility and the P.E.T. images are viewable on the Pegasys workstations in the nuclear medicine area.

The transfer of images from location to location is currently implemented by a process of exporting a patient's study (demographic data and images) from the workstation where it is acquired to the workstation where it is desired. Although this is a simple process to perform, it does require interaction with the workstations. Perhaps this technique will always be the case where image header translations need to be performed, but the transfers between the Pegasys workstations should become much easier with the newest version of software. This soon-to-be-released version will use a distributed database system with all patient data areas Network File System (NFS) mounted. This will allow a user

at any Pegasys workstation to examine the database of studies on all five workstations as though they were on the local disk. This will enable the physician who is reading to call up images for any patient from his workstation without unnecessary file system manipulation across the network. Since the images will be displayed from the disk where they reside, this also prevents the same images from being stored on the hard disk drives of multiple workstations.

Discussion

At the current time there have been no perceivable delays in transferring images over the network from station to station. It is yet to be determined what the traffic on the network will be when the physicians have access to images from any acquisition Pegasys without having to import them. The traffic on the network is expected to increase dramatically with the increased ease of access to the images.

At present, most of our acquisitions use a matrix of 64 x 64 for dynamic studies, though we are acquiring some of the dynamics at 128 x 128. Statics are acquired with a matrix of 128 x 128, and a matrix of 512 x 512 is used for whole-body acquisitions. All of these acquisitions are performed at a depth of 16 bits, since the Pegasys system determines if the data is less than 8 bits deep and if so only uses 8 bits for storage. The static matrix sizes were chosen in order to maintain contrast resolution; larger matrix sizes result in very few counts per pixel.

As the images are acquired and processed, they can be exported to the central "reading station." In SPECT thallium studies, the results are a set of six image series. These images are displayed in a predetermined format, and the slices are aligned by the technologist so that corresponding slices are adjacent (Figure 2). At this time it is not possible to transfer the repositioned images from one workstation to another. The technologist usually sets up the display and stores that window (display) as an icon on the edge of the CRT. The reading physician can then "pop up" the display with a single mouse button and do other minor manipulations (windowing, shift image slices, etc.) while reading. Since these icons cannot be transferred to the central reading station, the physicians go to the workstation where the processing took place. This will probably not change until the icon can be transferred to the physician's reading station.

The transfer of static images to the P.E.T. facility is a matter of converting the headers from the Interfile format to the Matrix format that is used by the CTI/Siemens P.E.T. Sun SPARC-2tm. The images are then displayed using the P.E.T. software. The reverse is true for images from P.E.T. to nuclear medicine. For transfer to PACS the headers are converted to ACR-NEMA version 2. Though at the current time ACR-NEMA does not support nuclear medicine images, static images can be given headers that our PACS will accept.

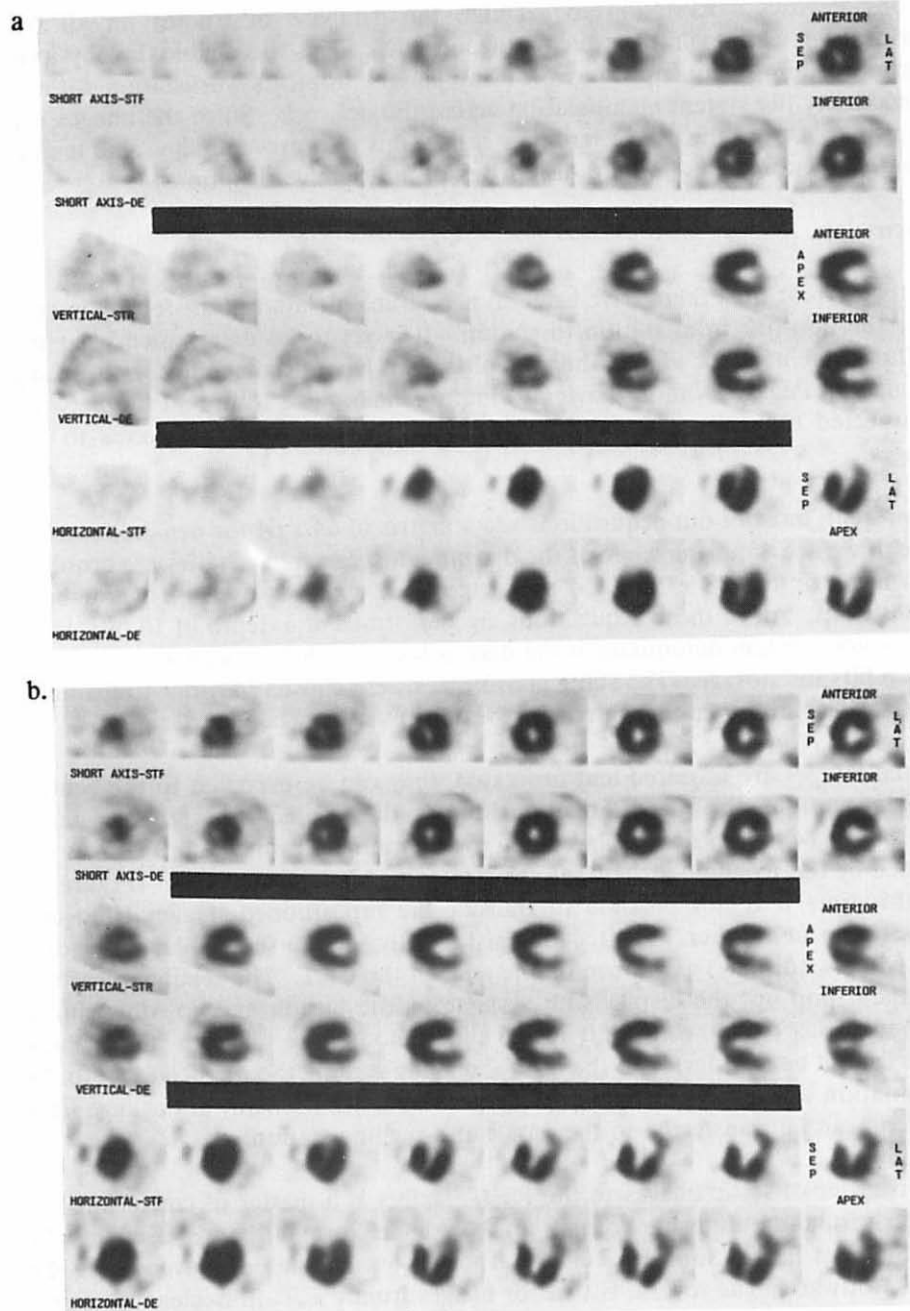


Figure 2. a) Six image sets as originally displayed by computer. b) Same six image sets after alignment and intensity modification.

Summary

We have found the digital nuclear medicine facility to be feasible. While at the current time we are not filmless, we are moving in that direction. Newer versions of software, including the distributed database, passing of icons, and redundancy in long-term storage will help us in archiving in the filmless department.

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Review of Image Storage Technologies and Devices: A Tutorial and Update

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An unresolved challenge of Image Management and Communication Systems (IMACS) is fast access to multiple images at reasonable cost. Several papers [2,7,8,9,10,14,17] have discussed strategies of digital image storage and there is general agreement that a combination of storage devices and storage methods must be used.

Requirements

If we start out with a department serving a 500 bed hospital we would find a distribution of daily procedures as shown Fig 1.

Modality	TOTAL		PROCEDURES				MB per DAY			
	proc/d	MB/d	Neur	other	DR	film	Neur	other	DR	film
Rad	248	3100.0				80 168			1000	2100
Rad/Contr	20	1000.0	2			10 8	100		500	00
Spec.Proc	8	320.0				6 2			240	80
CT	18	303.0	8	10			135	168		
DSA	10	160.0	2	8			32	128		
MRI	10	84.0	5	5			42	42		
US	20	360.0		20				360		
Nuc.Med	14	34.0	2	12			5	29		
sum	348	5361.0	19	55	96	178	314	727	1740	2580

Figure 1 Procedures and MB (Megabytes) per day for a PACS department
Films are assumed to be digitized at 5 MB

Radiographic procedures are still most numerous and the generated image data amount to more than 80 % of all data. The total daily production is 5.3 GB assuming that the film images will also be included after digitization. Fig 1 also suggests a breakdown of workstations into neuroradiological cases, digital radiographic cases (DR) and other cases as indicated. The DR workload could be handled by two storage phosphor systems. Per year such

a department would perform 87,000 procedures and accumulate 1.34 Terabytes of image data (a Terabyte is one million Megabytes or one thousand Gigabytes). An active-file storage should hold all cases during an average length of stay, i.e. 6 days, and would have a capacity of 32 GBs.

Access to image storage is critical at the beginning of the imaging process when image generating equipment such as CTs and MRs must not be slowed down by unresponsive storage devices. Fig 2 shows typical data generating rates of digital modalities. The fastest is DSA which produces up to 30 images per second of one quarter of a MB each, i.e. a data rate of 8 MB/sec. Ultrasound is almost as fast but has less critical resolution requirements. Nuclear medicine imaging for cardiac procedures produces a rate of 300 MB/sec while CT, MRI and DR are slowest.

MODALITY	INPUT MB	RATE kB/s	OUTPUT MB	RATE kB/s
Dig.Rad.	12.5	83	25	2000
DSA	16.0	8000	32	8000
CT	17.0	150	34	1000
MRI	8.0	18	16	1000
US	18.0	4000	18	4000
Nuc.Med.	2.5	300	5	1000

Figure 2 Digital Input and Output Quantities

The other stations which require fast image access are the diagnostic workstations where radiologists dictate reports. The conventional device is an auto-alternator which holds close to one hundred films premounted on several panels. Radiologist can inspect all films of a case with little delay and without being slowed down by the display system. Such high efficiency is only assured if all required images have been premounted. The digital equivalent of relevant film images of a case is 25 MB, or even more, and would require several high resolution, sophisticated monitors. Pilot studies have shown [3,11] that in order to achieve satisfactory electronic alternator performance a multiplicity of monitors are needed with a total cost far exceeding the cost of an alternator.

The ideal storage solution cannot be provided by a single type of device. Such a device should hold large data quantities (from 10 GB to 1000 GB). It should offer fast access (in the order of a fraction of a second), it must be stable and reliable, there should be little delay between write operation and read access (unlike films which require wet developing), it should be portable and, in order to be affordable and find widespread implementation, it should be inexpensive. Some storage devices offer a combinations of some

of these features but none meets all of the requirements.

Non-removable storage media

A fast and indispensable storage medium is solid state memory commonly called RAM (Random Access Memory). Such memory is used for general data and program storage but also as "frame buffers" which hold complete images for output to video displays. Frame buffers of 8 to 24 MBs are common in workstations. Not only are these memories nonremovable but they also lose data when power is removed. RAMS or Dynamic Random Access Memories (DRAMs) required periodic refreshing in order to retain the information.

A new type of solid state memory, based on ferroelectricity (FRAMs), will retain information even after loss of power [19]. A special pulse sequence writes the content of DRAMs into a backup FRAM memory. The reverse process restores the information in the DRAMs. Two advantages can be seen : large memory banks need not require large power sources if part of the memory can be put to sleep. Furthermore, memory banks can be unplugged and converted into removable memory. These FRAMs, however, are in the early development stages and not yet available for routine use.

A second important non-removable memory is rotating memory in the form of "Winchester" drives. These drives are now available with high capacity and low cost. 100 MB drives cost about \$ 400 and have a data rate of 1.5 MB/s. Parallel transfer disks (PTD) are particularly important for fast information transfer. They offer data rates beyond 8 MB/s and capacities well over 1 GB. They are the preferred storage devices for active case files.

RAID (Random Array of Inexpensive Disks) is a new development whereby several "inexpensive" disk drives are used in tandem [1,5]. The high speed data stream is split into several branches each one feeding one drive. The main advantage over a single multiplatter disk drive is increased reliability. By using more than the absolute minimum number of drives information can be reconstructed even if one drive fails. This technology will become increasingly important for the medical market.

Removable storage media

Figure 3 exhibits an overview of removable storage devices and a comparison of important characteristics. Floppy disks have made much progress and a small 3.5 " floppy holds four times the data quantity of an older 5.25 " floppy. The medium price is as low as 70 cents in larger quantities and the drive is

\$ 65 or less. For low level applications such as Teleradiology stations this is still a useful medium. New developments promise much increased capacity and also high data rate [13].

TYPE	capacity MB	Medium \$/MB	System \$k	Data rate MB/s	Access sec
Floppy	1.4	0.700	0.065	0.02	0.5
Mag.Disks	16	3.750	6	1.20	0.1
Opt.Disks	2600	0.200	30	0.25	0.2
MAO disks	650	0.325	5	0.50	0.1
Hel. Tape	5000	0.002	40	0.13	45.0
Opt. Tape	1000000	0.010	220	3.00	28.0
OT. Cartr	50000	0.005	30	3.00	0.6
Opt.JB	1020000	0.200	250	1.00	6.0
Cart. MT	86000	0.002	250	32.00	90.0

Figure 3 Comparison of removable media and devices
OT optical tape, MAO magneto-optical, JB Jukebox
MT magnetic tape

Removable disks as offered by Iomega (Bernulli drives) are more expensive but sustain a higher data rates. Optical disks (12" WORM) hold 2.6 GB and offer a data rate of .25 MB. There are signs of new developments both in terms of capacity and data rate. Kodak has developed a large 14 " 10.2 GB disk with a data rate of 1 MB. Erasable optical disk of the magneto-optical type have a capacity of up to 1 GB and a somewhat higher data rate than WORM drives. An interesting Japanese approach to PACS image traffic assigns an individual disk to every patient. This ISAC (Image Save And Carry) method avoids the complexities of a physical network [15]. In the US Polaroid has developed a similar concept and device.

Although the MAO storage method has found a large market and is widely used it is likely that other recording methods will replace it. The phase change method operates by differential cooling of spots heated by a laser beam. If the laser beam is highly concentrated the cooling proceeds very fast and does not permit crystallization. If the same energy is spread over a larger area cooling is slower and crystals form which increase the reflectivity of the spot. At very high energy levels this process turns nonreversible and produces ablation of the alloy just as WORM writing does.

Tape solutions, both of the magnetic and the optical type are offering interesting features. Helical tapes as used for video recording offer high data rates and low cost. Honeywell offers the VLDS with 5 GB capacity and 2 MB data rate [12] . Another product by Metrum Information Storage writes 14.5 GB at a rate of 2 MB/s at a lower cost than the VLDS. The cost per MB is

very low namely 0.2 cent. The system cost is relatively high and the bulk access is slow. Sony has developed the DR 1000 for high precision recording [16]. The large cassette holds 87 GB in a standard 19 mm format and offers a sustained data rate of 32 MB/sec. The cost, though, is high (\$ 250 k).

Two optical tape systems use the ICI "digital paper", a low cost material developed for magnetic recording but modified for optical use. CREO has developed a novel tape system which writes up to 3 MB/s in 32 parallel channels. 1 GB takes up only 1 m on the tape. The reel holds 1 TB of data.

Another novel device was developed by Laser Tape Systems [4]. The well proven IBM 3480 mechanism is used as transport but the write and read heads were modified for optical recording. A. Conover, president of Laser Tape Systems, stated recently, that recording rates of up to 15 MB/sec are achievable. This device could become very attractive for DSA and cardiac recording. A stacker for 10 units is also offered.

Finally, optical jukeboxes of various capacities and price levels are on the market. Kodak's system ADL 6800 can record up to 1.02 TB in the 100 platter configuration.

Integration and Segmentation

For an efficient and clinically useful PACS the various storage devices must be integrated. The focal point of such integration is the workplace of the radiologist namely the "electronic alternator". The mechanical alternator has been optimized through decades of radiology practice: information input is visual, information output is verbal. The speed of visual presentation of an electronic alternator must match that of the mechanical alternator. In order to accomplish such speed massive DRAMs must be applied in the form of frame buffers as well as fast disk systems in the form of PTDs or RAIDs. Prefetching of active cases must take place before the radiologist starts his work. Auto-routing will also be useful and may require artificial intelligence protocols. From this focal point the design of a PAC system can progress to other services.

Depending on the size and complexity of the department the image traffic should be segmented into clusters. Fig 1 indicates such a segmentation into neuroradiological, digital radiographic and general purpose clusters. Such clusters may have their own archives. In addition they will need access to a central long term archive. In spite of much progress with PACS technology and storage phosphor systems, routine radiographic imaging is still performed most efficiently and cost effectively with conventional methods. A conversion to fully filmless operation will most likely prove to be very expensive and failure-prone.

Commercial storage devices for digital modalities like CT, MRI, DSA and others are becoming faster and more reliable, while at the same time more affordable. The progress both with magnetic as well as optical storage technology is likely to continue.

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The Process Configuration Editor: A Tool for Keeping Up with a Changing PACS-Environment

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1.Introduction

Picture Archiving and Communication Systems (PACS) play a more and more important role in the organising tasks of radiological departments¹⁻⁴. The development of fast networks has led to the possibility of image transfer within the hospital and users from clinical departments have a direct and fast access to the images of radiological examinations.

At the Department of Radiology of the University of Graz, a PACS is used in daily routine. Our experiences show that the most urgent clinical interest in PACS is the availability of images in peripheral departments. Most departments of the hospital are connected by a hospitalwide network. To include new devices to the PACS and to enable an exchange of images we developed a tool which allows an easy expansion of the PACS software process structure. This means that new processes (for example for the image transfer to and the management of local databases etc.) can be added to the existing configuration without software changes in the already existing process structure. Via this tool, a standard process for a given application is selected and the logical address of the process and its partner processes, as well as the local environment (picture directories, local database etc.) where the process will be installed, are defined. The procedures which are necessary for a successful startup and running of the process are generated automatically and the process is logically connected to the PACS process structure. Then the process and its environment is physically installed.

2.PACS configuration

The PACS in the Department of Radiology of the University of Graz is used in daily routine for archiving, retrieval of images and image exchange within radiology^{5,6}. It includes as modalities 4 CT-scanners (one of them is located in the radiotherapy at a distance of approx. one km), a DSA, an MRI-scanner, 2 evaluation consoles, a radiotherapy planning system, an archive with 2 drives for optical disks, a diagnostic console with 3 high resolution monitors, one image display console and several image viewing consoles (based on PC). These components are connected by

two networks which are linked via a μ -VAX II: a hospitalwide network and a local network. Both networks have a bus topology and are based on Ethernet. The PACS is interfaced with a Radiological Information System (RIS) in that way, that the management of the archive is performed by the RIS.

3. PACS software process structures

The PACS is organized as a group of independent software processes which communicate with each other. These processes run in the background and execute various tasks such as the conversion of images into ACR-NEMA⁷ (the images are initially in a proprietary format), the transfer of images from the archive or the modalities to the local databases of the image display consoles, the management of local databases etc. The process structure is distributed over several computers. The communication between the processes is administrated by the Siemens PACSNET/SPI Toolkit, which complies with the ACR-NEMA/SPI commands to request and transfer images. First the processes are in a waiting state and must be activated by a command from another process. The processes work simultaneously and the sequence of processes operates as a pipeline (fig.1): while the last images of an examination are still being transferred over the network, the first images are already submitted into the database.

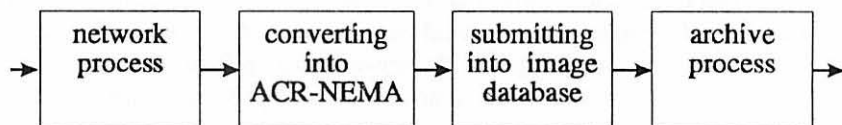


Fig. 1: process 'pipeline'

4. Experiences

From our point of view the most urgent clinical interest in PACS is not the primary diagnosis (reporting on the diagnostic console is still not accepted), but the availability of images in places where they are not yet available or only with time delays. (In the conventional film archive of our department 25-30% of the films are not available when requested). Therefore we concentrate our efforts on the activation of image transfer to the end users of the diagnostic information (neurosurgery, radiotherapy, pediatric surgery etc.) and on the exchange of images between the radiological departments (CT, MR, Nuclear Medicine etc.) within the hospital.

For these purposes new software processes must be installed which communicate with the already existing configuration. So the process structure of the PACS is not a static structure but a continually changing one.

5.The Process Configuration Editor

5.1.Components

We developed a tool for keeping up with this changing process structure. This tool allows an easy addition of new processes to the existing configuration. The tool includes:

- the Process Configuration Editor (PCE) which is used for the definition and installation of a process and its environment and its logical connection to the PACS.

- a set of standard processes for given applications (processes for the image transfer, administrator processes for the management of local databases for image viewing consoles etc.). The process communication is implemented with the SIEMENS PACSNET/SPI Toolkit and the PACSNET database, which contains the logical address of the process being used.

- the Process Configuration Structure (PCST) database which contains all the processes, their functions and their relations to each other (the process structure topology). The PCST database is logically connected to the PACSNET database.

5.2.Function

The Process Configuration Editor enables an extension of the PACS process structure by an interactive user dialogue. It allows the user to define logical addresses, to generate and provide the necessary software, to logically link a process to the process structure and to install the process and its environment physically on the target computer (fig. 2). The following operations are necessary for a successful installation of a new process.

Definitions: The logical addresses and logical names are defined. These are:

- 1) Process name
- 3) Process logical name
- 2) Network address

The local environment of the process (node name, device name, image directories, database directories etc.) are defined. The logical addresses of the processes (PACS Logical Address, PLA) are generated automatically out of the node name, the network address and the process logical name.

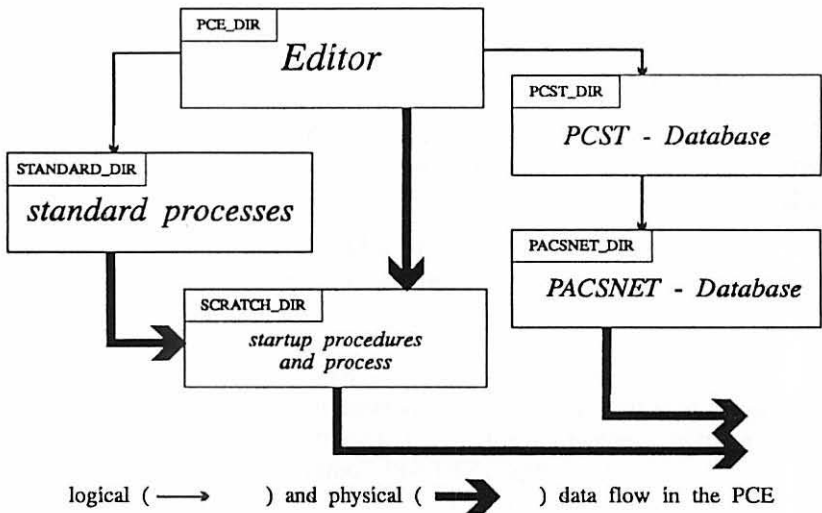


Fig. 2

Software generation and provision: The predefined process for a given application is selected and named. The procedures necessary for a successful startup and running of the process are generated automatically.

Logical connection: The logical address of the process, the node number and the station ID are inserted automatically into the PACSNET database using the PACSNET Configuration Functions. The logical address and the logical name of the process, its function (e.g. 'transfer process') and its partner processes are inserted into the PCST database and so the process structure topology in the Process Configuration Structure database is actualized automatically. Via the logical address (PLA) the PCST database is connected to the PACSNET database.

Physical installation: The directories needed on the target computer are created and then the process, its procedures and its environment are physically installed on the computer.

5.3. Logical connections and communication in the PACS

The startup procedures of the processes set the logical definitions of the process environment, the logical name and address of the process and its partner processes (fig. 3). The PACSNET network functions issue request messages, accept response messages and prepare to accept request messages. The network functions have access to the PACSNET database via the logical address of the process to

find the node name which is needed to open communication between the processes. The communication itself is a non-transparent task-to-task communication using DECnet as low layer protocol. The PACSNET database contains only the logical address and the node name of each process but no information about the relation between the processes. This information (the whole process structure) is contained in the PCST database. The PCST database is used as input for the archive process as well, so the archive automatically achieves information about new nodes, where images can be transferred to.

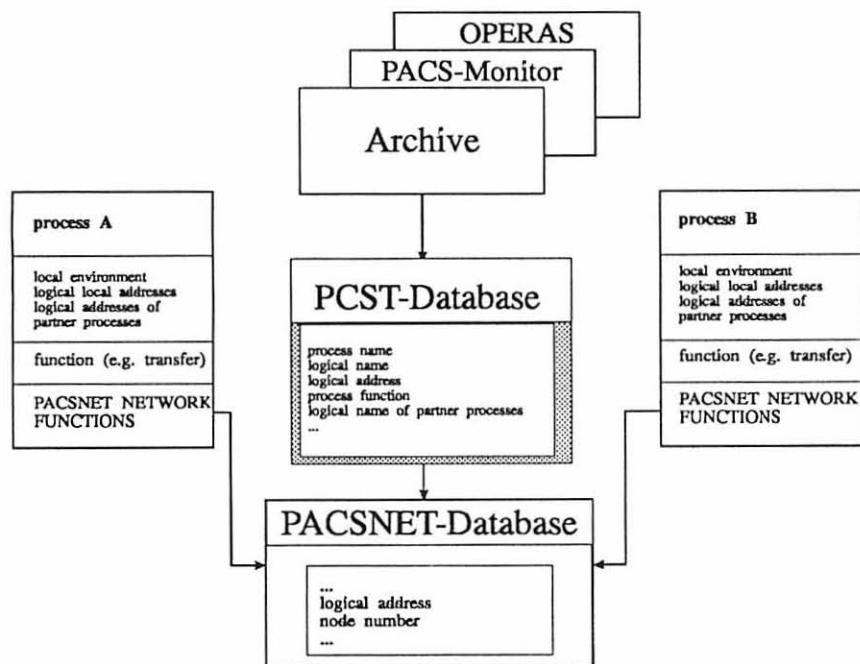


Fig. 3: logical connections in the PACS

The PCST database is also used as a resource for a software process (PACS-MONITOR), which is used for the handling and surveillance of the PACS, and for a rule-based expert system (OPERAS) which contains a set of heuristic rules for the detection of and recovering from the most frequent malfunctions which occur during the different operations in the PACS. Thus these utilities always have knowledge about the actual PACS configuration.

6. Application

We are installing image viewing consoles based on PCs in several departments (such as Radiotherapy, neuro surgery) of the hospital. These consoles are used for simple image display allowing a few image processing capabilities such

as windowing and pixel lense. The image viewing consoles enable the user an easy access to the images of the radiological examinations. The images can be transferred either from the archive or from a modality. To realize the image transfer to the viewing consoles we developed two standard processes which are defined, generated and installed via the PCE. The processes are running on VAX/VMS systems with DELQA interface.

The first process takes the images from the modality (at the moment we use MR images), converts them into the ACR-NEMA format, creates the overview images, the examination descriptor (patient name, examination number, number of images in the examination etc.) and transfers the images and the examination descriptor over the network.

The second process (administrator process) receives the images from the network and inserts them into the local database together with the examination description (The PC has access to the images on the VAX via the Network Operating software PCSA).

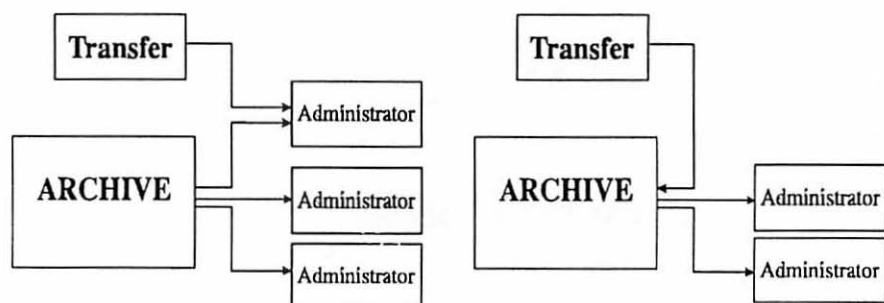


Fig.4: possible process structures

If the images are transferred from the archive, the archive process receives via the PCST database, information about the actual configuration and the processes, to where retrieved images should be transferred. Examples of possible configurations which are realized with these kind of processes are shown in fig. 4.

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The ACR-NEMA DICOM Standard: Information Model, Commands, and Network Protocols

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INTRODUCTION

The American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) in 1982 formed the ACR-NEMA committee to develop a standard to: Promote a generic digital image communication format; facilitate the development of picture archiving and communications systems (PACS); allow the creation of diagnostic databases for remote access; and help assure the useability of new equipment with existing systems (1,2).

Version 1 of the ACR-NEMA standard was published in 1985. The document was revised, new commands were added, and other organizational changes were incorporated into Version 2, published in 1988. The ACR-NEMA Standard for Digital Imaging and Communications in Medicine (Version 3: DICOM) is available in draft form from NEMA.

NEMA

The National Electrical Manufacturers Association is a voluntary trade association of 630 companies (in 1990) that manufacture products used in the generation, transmission, distribution, control and end-use of electricity (3). One of the association's key functions is the provision of an organizational framework for cooperative nonproprietary development of voluntary industrial standards and codes. It is through the MED-PACS subdivision of the Diagnostic Imaging and Therapy Systems Division that NEMA has worked jointly with the American College of Radiology (ACR) since 1982 to develop the ACR/NEMA Digital Imaging and Communications Standard.

COMPONENTS OF THE ACR-NEMA STANDARD: VERSION 1

An important part of communications is a set of standards which allow both parties to understand the meaning of what is being communicated. Figure 1 (next page) is an example of amateur radio communication between two individuals. It illustrates the use of standards in a communication protocol.

1. Is this frequency in use? WT4A
2. N4WQO N4WQO N4WQO this is WT4A, Whisky Tango Four Alpha, over.
3. WT4A this is N4WQO, receiving you 5 by 9, over.
4. Roger, N4WQO, receiving you 5 by 9 also. I have a message for you from N4QEE November Four Quebec Echo Echo, over.
5. Roger, WT4A, I understand the message is from N4QEE. Ready to copy, over.
6. N4WQO, the message is: N4QEE announces that she and her OM have added a new baby girl, Grace Anne, to the family, over.
7. WT4A, say again please, over.
8. Roger, N4WQO. N4QEE announces that she and her OM have added a new baby girl, Grace Anne, to the family, over.
9. WT4A, Roger that. I am very happy to hear the news, WT4A. I will tell KC4GTR and Emily also. Thank you. N4WQO Clear.
10. This is WT4A closing station.

Figure 1: This is the text of a brief voice communication between two amateur radio operators. The lines have been numbered for reference. In line 1, the operator whose call sign is WT4A is checking to see if the frequency is open. In line 2, WT4A is calling a specific station, N4WQO. Note the use of the international phonetic alphabet, and the termination of the segment with "over". In line 3, N4WQO replies, and uses a standard description for how well he is receiving the caller. "Roger" in line 4 is the phrase for "all received correctly". In line 6, a de facto standard abbreviation ("OM" for old man) has been used. Note in line 7 that N4WQO does not "Roger" WT4A, but asks for the segment to be repeated. In line 9, N4WQO closes his end of the message by stating "Clear". In line 10, WT4A terminates his session at his station.

Version 1 of the ACR-NEMA Digital Imaging and Communications Standard, published in 1985, established a reasonable common ground for users and vendors. The original Standard specifies a hardware interface, a data dictionary, and a set of commands. A Version 1 ACR-NEMA interface supports only point-to-point message transmission. Connection to a network requires additional hardware and software. Between two Version 1 interface cards, 16 bit bytes of data are sent in parallel over a 50-wire cable at up to 8 million bits per second (1). Accuracy is protected by an error-correction routine.

All Versions of the ACR-NEMA standard include a data dictionary -- a comprehensive table of rules for the encoding of information associated with images. Identifying information accompanies the image pixel data in a file area called the

header. An abbreviated header might contain the following information: Patient Name (encoded as a string of ASCII text characters), Patient ID (a free-format string of ASCII text or numerals), and Study Date (a text string having a defined format 'yyyy.mm.dd').

A minimal set of commands is provided to initiate transactions over the interface. They are listed with a summary of their functions in Table 1 (8). Each command has a *request* form and a *response* form. In addition to the definition of the command set, a protocol for message exchanges is defined in Version 1. The success or failure of a command *request* message is indicated by the value of a Status element within the command *response* message.

TABLE 1: DICOM Composite Commands	
COMMAND	FUNCTION
ECHO	Verification of connection.
SEND	Transmission of an Information Object Instance.
FIND	Inquiries about Information Object Instances.
GET	Transmission of an Information Object Instance via 3rd party application processes.
MOVE	Similar to GET, but end receiver is usually not the command initiator.
DIALOG	Communication of unformatted data.
CANCEL	Handling exceptions.

Field tests of Version 1 led to refinements which resulted in the publication of Version 2 of the ACR-NEMA standard being published in 1988. Ten years following the formation of the ACR-NEMA committee, devices conforming to Version 2 of the Standard are widely available.

MESSAGE STRUCTURE: ACR-NEMA VERSION 2

In the context of computer communications, a message is a stream of bits which represents information in transit from one device to another. Messages conforming to the semantic rules of the Version 2 ACR-NEMA Standard are composed of two parts: A command segment and a data segment. Individual units of information, called data elements, are organized within the data dictionary into related groups (Table 2, next page) (2).

Groups and elements are numbered. The pair of hexadecimal numbers (for example: 0010H,0020H) which designates a given group-element combination is a unique identification tag for that piece of information. The Version 2 ACR-NEMA Standard specifies that groups shall be transmitted in ascending order from the lowest to the highest group number (Table 3, on page 5) (2). Elements within each group

likewise are sent in ascending order. An element may be transmitted no more than once within a group. Groups are sent only once per message.

As it appears in a message, each individual data element consists of its group-element tag, its length, and its value. The length of every element and group is rounded to an even number to facilitate automatic error checking. An odd length detected at the receiving end is evidence of damage to the dataset. From the user's point of view, the element values are the most essential part of the message. Entries representing data values must be coded into proper syntax (ASCII text, ASCII numerals, or binary). The ACR-NEMA Version 2 data dictionary syntax rules are identical to those of Version 1. In both Versions, a Type designation indicates the priority of each element. A typical data dictionary entry is depicted in Table 4 (on page 5) (2).

Group 0000H is the command group. Most of its elements are type 1 (required). The priority designation of elements in the command group varies in a defined way, according to the type of command -- since each command performs a different function. ACR-NEMA Version 2 commands are linked with three classes of datasets: Image, text, and graphics. The Standard defines the set of information elements which comprise each class.

TABLE 2: DICOM DATA ELEMENT GROUPS

GROUP NUMBER and NAME		TYPICAL DATA ELEMENTS
0000H	Command	Command type, Message ID, Dataset type...
0008H	Identifying	Data and time of study. Radiologist's name...
0010H	Patient	Patient's name, ID numbers, birthdate...
0018H	Acquisition	Contrast agent, slice thickness, radionuclide...
0020H	Relationship	Slice location, study #, series #, acquisition #...
0028H	Image Presentation	Rows, columns, pixel size, grey scale...
4000H	Text	Free-format ASCII text characters...
6000H	Overlay	Region of interest (ROI), overlay format...
7FE0H	Pixel Data	The actual image, pixel by pixel...

TABLE 3: MESSAGE SYNTAX of VERSION 2 ACR-NEMA

The group 0000 elements are sent first... then the data elements follow.	
COMMAND	DATA VALUES
Group 0000: Element1, element2, element3...	Group 0008: Element1, element2, element3... Group 0010: Element1, element2, element3... ...and so on through all of the groups and elements for which values must be communicated...

TABLE 4: SAMPLE DATA DICTIONARY ENTRY

GROUP	ELEMENT	NAME	VALUE REPRESENTATION
0028H	0100H	Bits Allocated	BI (<i>Binary</i>)

VALUE TYPES	VALUE MULTIPLICITY	ELEMENT TYPE	DEFAULT VALUE
HX (<i>Hexadecimal</i>)	S (<i>Single value</i>)	1D (<i>Required element with a default value defined</i>)	0016

DEFINITION	Maximum bits allocated for any pixel
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Image pixel data is carried as multiple values within one element: 7FE0H, 0010H (Pixel Data; binary, defined format, multiple value, type 1). The byte order is reversed intentionally, due to the data-handling specifications of the Standard. For an MRI image (512 by 512 matrix; two 8-bit bytes per pixel) the ratio of header information to image data is less than 1:1000. However, the proportion jumps to over 30% when using the same header for Nuclear Medicine dynamic images with matrix size of 32 by 32. This is an unacceptable amount of overhead, since Version 2 requires a full header to be sent with each image.

DICOM -- DIGITAL IMAGING AND COMMUNICATIONS IN MEDICINE

The incorporation of an object-oriented data model and the addition of support for ISO Standard communications substantially broaden the scope of the DICOM Standard. The draft document of the Standard is composed of nine parts (Table 5: Next page) (2). Parts 1 and 8 of DICOM have been released for comment, prior to balloting by NEMA. The remaining seven parts are scheduled to be circulated for comment in the December, 1992. The modular design of DICOM facilitates editing and future enhancements of the Standard (4).

TABLE 5: THE NINE PARTS OF THE DICOM STANDARD

Part 1: Introduction and Overview	Introduction, history and future directions; goals, rationale, and technical description of the parts of the standard
Part 2: Conformance	Requirements for functional, messaging, encoding, and network conformance; structure of a conformance claim
Part 3: Information Objects	The set of information objects referenced in service class specifications, attribute list, and semantics of definitions
Part 4: Service Classes	Semantics of a command as applied to a data set in a given context. Definition of the object attributes required for a given transaction.
Part 5: Data Interchange Formats	Details of data structure and semantics, syntax, usage, compounding of data sets, and basic and advanced functions
Part 6: Data Dictionary	Attributes of information objects classified by group and element number, name, and parameters; description of permitted values
Part 7: Message Exchange Protocol	Examples of command exchanges in both point-to-point and ISO contexts, protocol for command encoding and status indication
Part 8: Network Interface	Definition of a generic upper-layer service common to both OSI and TCP-IP environments, supporting standard networks
Part 9: Point-to-Point Interface	Definition of 50-pin interface, physical protocol, data link frame protocol, virtual channels, and session layer services

THE ISO REFERENCE MODEL

The software model of the DICOM interface follows the International Standards Organization reference model for network communications (ISORM) (Table 6: Next page) (2,5). The ISO reference model incorporates the concept of cooperating peer service users linked transparently by a service provider. Protocols based on the ISORM control the process of information exchange among dissimilar computer systems. A sequence of protocol negotiations mediate the differing abilities and requirements of devices and software applications linked remotely by a network. ISO publications describe the ISORM in detail. The structure of messages; the negotiation of services among remote users; and the resolution of errors and conflicts are some of the key topics.

Radiology imaging software applications operate at level 7 of the ISORM, using the top layer of the so-called ISO protocol "stack". The user of the system interacts only with the application program. Whether a graphical user interface or a command-line interpreter is provided, the application program is entirely responsible for the "feel" of the system. The application layer and presentation layer software entities are responsible for information handling. The lower layers are concerned only with the reliable transmission of data. Commands or data entered by the initiating user are passed down to the ISO communications software for transmission to the responding user, (either a person or a device).

NETWORK CONNECTIVITY OPTIONS:

Electronic communications networks generally operate at a basic level with one of three types of protocol. The simplest type to consider is the contention protocol. In this method of communicating, a device simply transmits data when it has it to send. Provided no other device has done so simultaneously, the data will reach its intended receiver uncorrupted. If two devices overlap in transmission, the data from both will be corrupted. Check sequences put into the data to be sent allow such collisions to be detected. In the simplest contention protocol, both devices back off for a random time before trying to re-transmit. A modification of their protocol reduces the chances of collisions by having the devices listen to the network for activity before transmitting. In this instance, collisions can occur only if a device begins transmitting even though there is another device which began transmission very shortly before, but the electronic signal has not yet reached the second transmitter (6,7,8).

The second major protocol type avoids collisions altogether. These collision-free, or non-contention protocols work by allowing only one device at a time to transmit. Examples of administration of collision-free protocols are by having a central device allocate transmission time, by circulating a message in which each device with data to transmit inserts an indicator, and by circulating a token which is seized by devices with data to transmit (6,7,8).

A third protocol class is the limited-contention type. These protocols have features of both contention and collision-free methods (6). When network load is low, contention protocols are most efficient. The probability of a collision is low, so most devices will be able to transmit their data without having to re-transmit because of collisions. As the load increases, the number of collisions increases, and the efficiency drops. Contention-free protocols have nearly the inverse behavior. With low load the overhead of the protocol results in inefficiency, since the token or other

TABLE 6: THE ISO REFERENCE MODEL
INFORMATION HANDLING LAYERS

<i>Level 7:</i> APPLICATION	Contains both the user interface software and the input/output routines of the generic communications software. Establishes associations with peer application processes. Preserves the relationships between information units.
<i>Level 6:</i> PRESENTATION	Translates information units from the syntax of the Application layer to the transfer syntax negotiated with a peer Presentation layer across the network. The size of transferred information units is not constrained by the internal details of network function.

DATA HANDLING LAYERS

<i>Level 5:</i> SESSION	Establishes and controls connections. Segments the information units (of arbitrary size) provided by the Presentation layer into manageable dialogue units of data, the size of which is constrained only by the capabilities of the Transport service.
<i>Level 4:</i> TRANSPORT	Provides reliable end-to-end transfer of Session dialogue units regardless of the type of Network employed. Ensures that speed, accuracy, and reliability meet levels specified by the Session layer.
<i>Level 3:</i> NETWORK	Routes and relays data units. Assigns virtual channels. Encapsulates data into packets and adds addresses and sequence numbers to each. Negotiates handoffs between intermediate relay points to support the Transport layer.
<i>Level 2:</i> DATA LINK	Frames each packet between a control word and a frame check word. Facilitates error correction. Sends frames to the hardware of the Physical layer only upon receipt of the proper status indication.
<i>Level 1:</i> PHYSICAL	Transmits frames created by the Data Link layer by generating electrical or optical impulses, or other signals, according to the timing, duration, and amplitude protocols demanded by the type of network employed.

Table 6. This is the seven-layer reference model for computer communications developed by the International Standards Organization. Each layer receives services from the layer immediately below it and provides services to the layer above it. Note the separation of the information-handling upper layers and the data-handling lower layers. Although functional flow here is described only from the "top down", the reciprocal occurs when data is received by the Physical layer for delivery to the top. Each layer also operates in tandem with its peer across the network (Application with Application, Presentation with Presentation, and so on) (2).

NETWORK CONNECTIVITY (continued from page 7)

controlling message moves through the network continuously, and a device with data to transmit will have to wait for it. All the devices at least "look" at the token, even if they do not have data to send. At high load, however, the absence of collisions means that re-transmission will not have to be done. These different behaviors under load are the reason for the limited-contention techniques which operate like contention protocols at low load and collision-free protocols at higher load.

A network supporting a PACS is usually of the local area network (LAN) variety. However, with increasing interest in long-distance communication for support of teleradiology, educational programs, and research, networks of the metropolitan area (MAN) and wide area (WAN) size need to be considered. In general, extending communications to the MAN and WAN scale involves using common carriers. Even though the cost of fast data transmission service is high and the time lag between the development of new technology and its implementation by the carrier is long, common carriers provide the advantages of extensive maintenance, generally high reliability, and a range of services.

The nature of communication dictates that some standards be followed if the process is to be successful. The radiology department wishing to implement a PACS may use various standards as they apply to networks (such as Ethernet -- one form of Carrier Sense Multiple Access with Collision Detection, IEEE Standard 802.3, ISO Standard 8802.3). One of the major communications problems faced by the PACS implementer, however, is not the network. Most radiology departments have imaging equipment from multiple vendors. It is the interfacing of these devices to the network that is a challenge. Each vendor tends to view the digital data format used by the imaging equipment as proprietary. The main goal of the ACR-NEMA Digital Imaging and Communications Standards Committee is to develop a standard which allow users to extract digital images and associated information from equipment in a well-described, public-domain manner.

The DICOM standard, represents a major conceptual departure from the limited point-to-point communications goal of Versions 1 and 2 of the ACR-NEMA Standard. While maintaining compatibility with the 50-pin physical connector and the signalling protocol of the original Standard, DICOM specifies means of alternative connections which simplify multi-point networking. The DICOM standard simplifies network connections by defining an Upper Layer Service which supports two widely-used communications standards: OSI and TCP-IP protocols (Figure 2, next page).

The new Upper Layer Service supports TCP-IP (Transmission Control Protocol - Internet Protocol) software, which can control communications between devices using inexpensive and widely-available Ethernet interface cards (9,10). Versions of TCP-IP are available for essentially any hardware platform one is likely to use today, and for a broad range of network configurations. The generic upper layer service also supports a subset of the ISORM protocols, which are becoming available now as commercial products.

FIGURE 2: DICOM NETWORK CONNECTIVITY OPTIONS

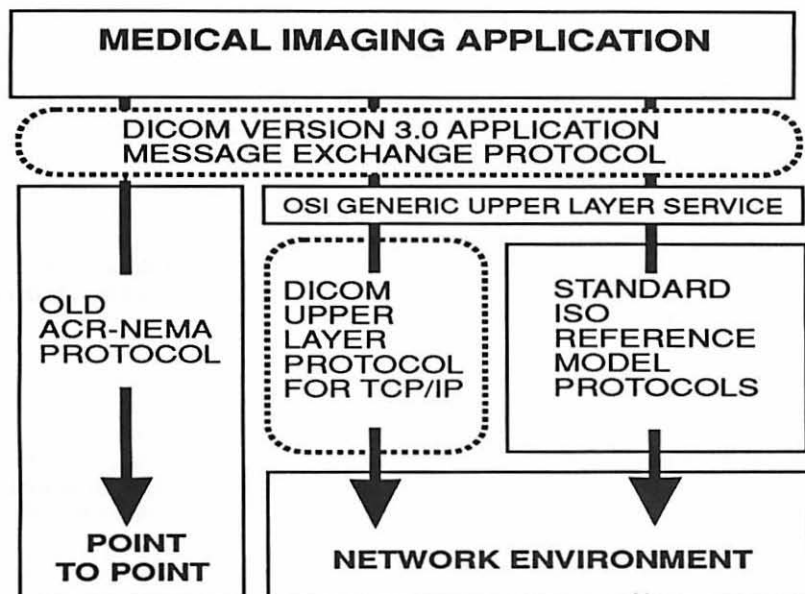


Figure 2. Bold arrows indicate the three alternative communications pathways supported by the DICOM Version 3.0 Standard. Groups of related software layers are boxed together. Dotted lines represent new protocols developed for DICOM. The generic upper layer service is designed to allow systems to migrate from TCP/IP to OSI without changes in the application message exchange protocol. A wide variety of standard network configurations are supported as well as the original 50-pin ACR-NEMA point-to-point connection.

FOLDERS AND FILE LINKING:

The PAPHYRUS file format developed at the University Hospital of Geneva is a method for grouping associated images under Version 2 of the ACR-NEMA Standard. Images are assigned to folders by value (containing actual images or other data) and folders by reference (containing only the memory addresses of the actual datasets) (11). The folder concept of PAPHYRUS is blended with ACR-NEMA message structure by way of a user-defined Group 0041H, which contains the addresses of the related datasets.

The draft Version 3 of the DICOM Standard incorporates a mechanism for linking related images to a single identification header during transport. Working Group VI of the ACR-NEMA Committee is considering the final form of the message folder structure to eliminate repetition of identical data elements. The reduction of redundancy will be significant, particularly in nuclear medicine. ISO protocols for hierarchical directory structure, remote use of storage resources, and selection of multiple files by logical 'filters' also are available as needed to extend future Versions of DICOM (12,13).

INFORMATION MODELLING: OBJECT-ORIENTED ANALYSIS

In the process of developing the DICOM standard, the ACR and NEMA jointly have taken the difficult first steps toward the complete reorganization of the information model on which Versions 1 and 2 of the ACR-NEMA standard were based. Tools of object oriented analysis have been used to refine the standard data dictionary developed for Versions 1 and 2 and to identify the characteristics of key entities in the domain of medical imaging.

The purpose of an information model is to identify, classify, abstract essential relationships, and organize information into a formal structure. Similar "things, or instances, are identified and abstracted as objects; characteristics of these instances are abstracted as attributes; and reliable associations between the instances are abstracted as relationships (14)."

Information modelling reduces redundancy and ambiguity by requiring that information objects be defined only in terms of their most fundamental and unchanging qualities and/or values -- their lowest common denominators. Related but not identical types of entities are grouped into information object classes. An instance of an object class is an individual member of the class type. Properties of inheritance and hierarchy determine the attributes of objects, their superclasses, and subclasses.

There is no overlap or duplication of attributes among the superclass of normalized information object classes (6). However, another superclass of composite information objects are permitted to share some attributes which may have identical Group-Element tags. These objects have been defined to contain the imaging modality information found in the data dictionary of Versions 1 and 2. Examples of composite information object classes include the MR Image Information Object Class and the Ultrasound Image Information Object Class. Their attributes are grouped in modules which are assembled in a generic manner. Their existence represents a logical compromise made to provide upward compatibility to systems still using ACR-NEMA Versions 1 or 2. Future Versions of DICOM will migrate away from composite information objects toward normalized information objects.

A unique identifier value (UID) is assigned to each class of information object. The value consists of a prefix assigned by an ISO member organization and a suffix assigned by the local organization (i.e. hospital, imaging center, or office). Each local organization is responsible for developing its own unique coding system for UID suffixes. Standardization of object class enumeration is intended to enforce compatibility among information models. Unique identifiers are assigned by a similar protocol to each information object instance also. The prefix uniquely identifies a particular organization. The suffix is unique within that organization for a particular individual. The union of the two parts is a globally unique ID number (barring coding errors). The information object class and information object instance UID values are carried in two new Group 0008H data elements defined for DICOM.

THE DICOM COMMANDS

The commands supported in DICOM for compatibility with Versions 1 and 2, operate with composite information objects and are called composite commands. Table 1 is a list of the composite commands with a brief description of their functions. The commands defined for DICOM are a subset of the commands defined for the network management services of the application layer of ISO OSI. These are defined

in an ISO standard for common management service (CMIS) (ISO 9595 Common Management Information Service Description) (13). While CMIS defines the services supported, the commands use service elements (CMISE) which are those structures carrying the information for the command syntax. These CMIS commands in DICOM operate only with normalized information object classes, and are called normalized commands. Because network management is usually done in connection-oriented manner, these commands rely on the establishment of a connection (or association in OSI terminology) between two network connected entities (7). There is also an ISO standard service which provides control over such associations, and is used by the service elements of the CMIS commands. This is called the association control service element (ACSE) and is described by ISO 8649 and ISO 8650 (7). DICOM uses ACSE for support of its normalized commands. Table 7 is a listing of the DICOM normalized commands with brief functional descriptions (8).

TABLE 7: DICOM NORMALIZED COMMANDS

COMMAND	FUNCTION
M_EVENT_REPORT	Information object-related event notification.
M_GET	Information object attribute value retrieval.
M_SET	Information object attribute value specification.
M_ACTION	Information object-related action specification.
M_CREATE	Create an information object.
M_DELETE	Delete an information object.

CONFORMANCE AND INTEROPERABILITY

Missing from the early Versions of the ACR-NEMA standard is a rigorous treatment of the issue of conformance. Thus, ambiguity has existed among various interpretations of the earlier Versions. Troublesome incompatibilities have been experienced by users particularly in the areas of unique identification numbers, orientation coordinates of cross-sectional images, and examination hierarchy (study, acquisition, series, image). Interoperation implies that connected devices not only interchange information (supportable through Versions 1 and 2), but instructions on what to do with, and messages about what has been done to, the information. The defined information objects and commands of Version 3 together will support communication *and* interoperation of equipment connected using one of the DICOM network specifications (2,15).

DICOM approaches the issues of conformance and interoperability through the mechanism of the service class (16). A service class is a set of services provided by a service class provider (SCP) to a service class user (SCU) over an association. The detailed specification of the service class is called a service class specification. It defines, in abstract terms, the service supported and the required and optional

attributes of all commands and information objects exchanged between the SCP and SCU in supporting the service. The service class specification does not define how the service class is to be implemented. Table 8 lists the draft service classes of DICOM (8).

TABLE 8: DRAFT DICOM SERVICE CLASSES

IMAGE STORAGE	Provides storage for datasets.
IMAGE QUERY	Supports inquiries about datasets.
IMAGE RETRIEVAL	Supports retrieval of datasets from storage.
IMAGE PRINT	Supports hard-copy generation.
EXAM MANAGEMENT	Supports management of studies (which may consist of several series of images).
STORAGE RESOURCE	Supports management of the network data-storage resource.

An advantage of the service class approach is that it forms the nucleus of the conformance claim. Such a claim is structured according to Part 2 of DICOM, and will allow a manufacturer to detail exactly what service classes are supported, and which, if any, optional features are implemented (16). The goal of the conformance claim is to allow an analysis of how two devices, each with conformance claims, will interoperate.

HARMONIZATION WITH OTHER STANDARDS

Radiology has its own "language". By careful application of data modelling principles, one can discover essential units of information (objects, attributes) and fundamental functional needs (service classes, procedures, methods) and classify them into a precise structure. All communication across a computer interface to or from Radiology obeys either explicit or implicit semantic rules and involves an intentional choice of data syntax. Mutual agreement on an information model is the first step toward harmonization of two different information-exchange standards. Achieving this harmonization on a large scale could strongly enhance the availability of clinical records for timely use in patient care.

Several organizations have worked out detailed information models for various aspects of medical data processing. Automatic communication of results from laboratory equipment is possible using specifications developed by the Association for Testing Materials (ASTM). The Institute for Electrical and Electronics Engineers (IEEE) has developed the P1073 Medical Information Bus and MEDIX protocols, which are specifications for interfacing medical applications running on computers different types (17). HL7 is another widely used voluntary standard for format and protocol of text message exchanges (18). International cooperative efforts involving the Japanese MIPS standard (19) and the European CEN Technical Committee 251 have been productive (20).

INTERNATIONAL STANDARDIZATION:

The International Standards Organization (ISO) and International Electrotechnical Commission (IEC) together form a system for international standardization in conjunction with national standards organizations from around the globe. The American National Standards Institute (ANSI) is the largest of the member national organizations in North America. Due to the efforts of these influential organizations, the ISO-IEC standards are rapidly being adopted by several nations, including the United States (GOSIP: GOVERNMENT Standard Information Profile), as government network standards (17). A representative of the ACR-NEMA Digital Imaging and Communications Standards Committee now reports directly to ANSI through its Healthcare Informatics Standards Planning Panel (21). The ACR-NEMA committee is preparing to submit DICOM through ANSI to the ISO as a draft international standard for communication of medical images.

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SESSION 16

Workstations

Chair: Yongmin Kim

A Foundation for a Formal Model to Describe the Film Interpretation Process

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Abstract

Many functional, technical and perceptual conditions must be met before a workstation will be adequate for primary diagnosis. The focus of this paper is on the functional aspects of the workstation. A serious problem with the digital workstation is the limited display area. A limited display area forces the radiologist to manipulate the arrangement of the images on the display many times during a typical study in order to make necessary comparisons. Presently, few manipulations are necessary since display area is abundant and many images are continuously available.

We hypothesize that it is possible to describe the film interpretation process as a set of well defined states that represent the display combinations necessary for diagnosis. Identifying these states and determining their interaction will enable us to formally model the film interpretation process.

To determine the existence of the primary building blocks of this model, the well defined states, we have conducted a preliminary investigation. The results of this investigation indicate that well defined states exist and that they are consistent within and between radiologists for at least some film interpretation processes.

This paper describes the results of our investigation and describes some implications of this model for diagnostic workstation design.

1. Introduction

Throughout the history of PACS research, the need for intelligent systems to assist the radiologist in the functional aspects of the diagnostic process has been well documented. Early researchers no-

ticed the need for prefetching and preloading schemes to assist the radiologist [e.g. van der Voorde 1986, Kasday 1986]. More recently, researchers have recognized the need for tools that assist the radiologist throughout the diagnostic process [e.g. Arenson 1990, Beard 1990, Haynor 1990, Pizer 1989, Wendler 1991]. These tools would both determine the original placement of the images and provide the radiologist with an easily understood model of the operation of the system. In order to accomplish this, it is first necessary to understand the tasks that are to be performed at the workstation.

Acquiring knowledge about the functional aspects diagnostic process and representing the knowledge in a format that provides useful information is still problem for researchers in this area [e.g. Wendler 1991, Pizer 1990]. This task is complicated because there are many variables that influence the diagnostic process. Some of these variables, although critical for accurate diagnosis, many not effect the process at a functional level and we would like a process representation independent of these variables. By eliminating consideration of non-functional aspects, we can attempt to verify that the diagnostic process involves some fixed patterns of behavior at the functional level.

We propose that the film interpretation process can be described as a series of states, with each state representing the data that is displayed simultaneously. Using a state transition diagram [Wasserman 1985] to model the reading process we hope to reveal patterns in the radiologists behavior. Recognizing these patterns will enable us to build tools to enhance the radiologist's efficiency in many areas of the diagnostic process. But first, it is necessary for us to determine if a state-based representation can adequately capture the dynamics of the diagnostic process. To do this, we have conducted an investigation to determine 1) if the number of display states used by the radiologist in the diagnostic process is small enough to provide useful information, and 2) if any patterns exist in the way the radiologist sequences through the display states. The following is a description of the investigation and a discussion of the results.

2. Procedure

Two senior faculty radiologists, with more than 20 years of experience each, participated in this investigation. The radiologists were observed while interpreting a combined total of 176 chest studies over a six day period, with the first radiologist interpreting 99 cases and the second radiologist interpreting 77 cases. As will be explained, special care was taken to insure that the types of cases interpreted represented the range of study types and disease patterns normally encountered in our radiology department.

To capture the actual reading process, with as little interruption from our investigation as possible, the observed cases were a part of the radiologists' daily workload. All of the chest cases scheduled to be read in the observed batch were observed and included in the data.

In our department, adult chest cases are interpreted at three film alternators. Two of the alternators are used for inpatient cases. The third alternator is used for outpatient cases. Typically, the type of studies performed for inpatients and outpatients are slightly different, with more single film studies being performed for inpatients. Because of this, the interpretation process for inpatient and outpatient reading was observed for both radiologists, with approximately half of the studies for each radiologist coming from the inpatient reading environment and half coming from outpatient reading.

During the observation process, each radiologist was instructed that only two images could be viewed simultaneously. To enforce this limitation the radiologist was only allowed to illuminate the two images that were currently being viewed. In addition, the eye and head movements of the radiologist were monitored to determine if films that were not illuminated were being viewed. If the radiologist's focus was seen to change without the radiologist changing the display illumination, this change was recorded by the observer.

The observer sequentially recorded which images were displayed simultaneously. The results follow.

3. Results

Figure 1 reports the display states used by the radiologist for approximately 98% of the observed cases. The first column identifies the display state. The second column represents the display states with each state listed as the image pair displayed simultaneously. In this notation C is used to represent the current study. C-n represents a previous study where n is the offset of the represented study from the current study (e.g. C-2 means the image came from a study two studies before the current study). The second and third columns list the percentage of time each radiologist viewed this particular display state. The fourth column lists the overall percentage this display state was observed.

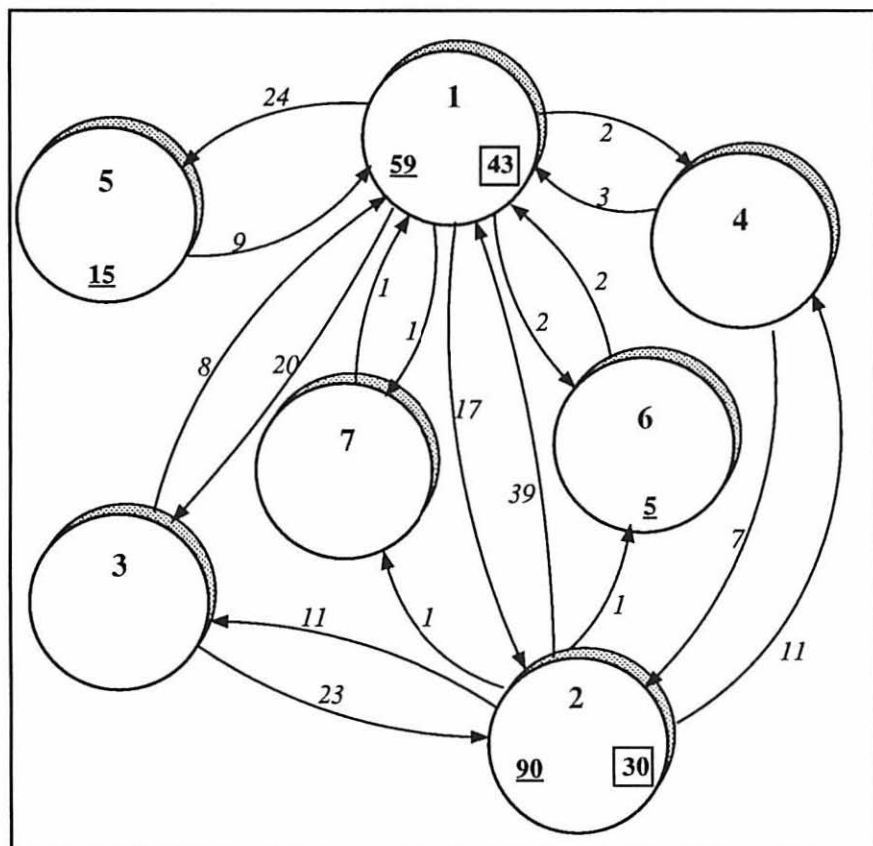
Figure 1 Display States

Id.	State	Radiologist		Overall %
		1	2	
1	(C PA C-1 PA)	42.65	31.98	37.77
2	(C Lat C PA)	35.29	39.53	37.23
3	(C Lat C-1 Lat)	9.80	6.98	8.51
4	(C-1 PA C-2 PA)	.98	7.55	3.98
5	(C-1 Lat C-1 PA)	6.96	6.98	6.91
6	(C+1 PA C PA)	2.45	1.74	2.13
7	(C PA C-2 PA)	.49	2.33	1.33
	<i>Total States</i>	<i>98.13</i>	<i>97.09</i>	<i>97.86</i>

Figure 2 provides information regarding the sequencing of states in the diagnostic process. Each state is represented by the number from Figure 1. In some instances, the original display state was sufficient to complete the diagnostic process. This occurrence is represented on this diagram as a count within a box in the corresponding

state circle. Initial states are represented by the underlined count within the state circle. The total number of transitions observed was 278. This number is higher than the number of cases observed because multiple transitions can occur within a case. This diagram represents 91.72% of transitions observed.

Figure 2 State Transition diagram



4. Discussion

The purpose of this investigation was to determine if describing the diagnostic process in terms of display states could provide a manageable representation of the process. Based on these preliminary results we are encouraged that this type of a representation can provide useful information regarding the functional aspects of the proc-

ess. A key benefit of this representation is that actual reading patterns that may be obscured by non-functional aspects of the process can be recognized.

Based on this foundation we are continuing work on this model by

- 1) applying algorithms to determine if some consistent environmental factors influence the transitions between display patterns and
- 2) expanding the model to include more radiologists in different reading environments.

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A Time-Motion Comparison of Several Radiology Workstation Designs and Film

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1. INTRODUCTION

What are the relative effects of screen space and system response time on the speed of an accurate CT chest study interpretation? Screen space refers to the number of full resolution images of a given size that can be simultaneously displayed on a radiology workstation's screens. System response time refers to that portion of the total interpretation time during which the radiologist has to wait for the computer to complete an operation such as filling a monitor with images. This question is critical to the radiology workstation designer who must decide whether to add more or larger monitors, use a faster computer, or redesign the interface, and critical to the radiologist deciding whether a given workstation design will be viable in the clinic. Prototypes and observer studies are the ideal method of comparison. However, prototypes and observer studies can be very time consuming, and often even crude time motion models are sufficient to make reasonable design decisions.

We first describe time-motion analysis methods focusing on Card, Moran, and Newell's Keystroke and GOMS models. Second, we present a generic CT study and scenario for single CT study interpretation. Third, we describe the nine different image viewing systems, and fourth, we present the results of our models for these nine systems. Several systems are compared with observer study data. Fifth and last, we discuss the implementation of the model results for workstation design.

2. BACKGROUND

While time motion analysis techniques¹ have been around since the turn of the century for analyzing repetitive tasks requiring minimal mental effort, only recently have these techniques been expanded to include tasks that require choice in methodology. Card, Moran, and Newell's Keystroke² and GOMS³ (goals, operators, methods, and selection rules) models have proven to be fairly effective in describing experts using computer tools such as text editors to conduct decision-intensive tasks such as correcting a document. These models estimate the completion time for a task by summing the completion times of its subtasks which are in turn recursively analyzed until apriori tasks such as button presses are encountered. Task times for these atomic tasks can either be located in a table or determined by observation of users in-

teracting with miniature, highly focused interface mockups. Table 1 gives some times for several typical atomic tasks.

Atomic Task	Average
Press button	0.1 seconds
Type, per character	0.2 seconds
Point cursor at object with mouse	1.1 seconds
Move hand from keyboard to mouse	0.4 seconds

Table 1
Typical Task Times

An example may be helpful. Suppose a workstation can display a single CT image at a time and has an interface consisting of two buttons, one for scrolling forward and one for scrolling backwards through the study. We will assume a system response time of 0.5 seconds and an average of 41 slices in the CT study. If users wished to locate a slice containing a particular anatomical object, they would have to scroll backwards or forwards to move to the appropriate slice. We will assume that on average, the search will start at the middle of the study, and that on average, the users must scroll 10 times to locate the desired slice.

To scroll once, the user must press the appropriate button (0.1 seconds) and wait for the system to respond (0.5 seconds) resulting in 0.6 seconds per scroll for a total of 6 seconds for this ten-scroll task. What If the system response time for a single scroll was 3.5 seconds or 0.1 seconds? then the task time would be 36 seconds and 2 seconds respectively. (Those of you who have experience with time-motion analysis realize that the above discussion is highly simplified. For example, real users mentally pause to decide what operations to perform and how to perform them, and both mental pauses and physical movements like button presses can be concurrent with system response time. While the models used later in the paper included these considerations, we will avoid their discussion for the sake of simplicity and clarity.)

These time motion models are neither designed for, nor easily model information retrieval-and-analysis tasks – including medical image interpretation – for they cannot account for the time the radiologist will spend viewing the various images. Nevertheless, these models can account for the image manipulation time of a given workstation design and compare it against the image manipulation time of another. By assuming the the image viewing time will be constant across image viewing systems, we can use the models to roughly estimate task time for a system.

3. SINGLE CT CHEST INTERPRETATION

3.1 Generic Single CT Interpretation scenario

Comparisons of CT workstations are highly dependent on the task used in the analysis. For example if the CT study only contained eight slices, the analysis might un-

realistically favor a workstation with 2 1Kx1K monitors (holding eight full resolution CT images) and a 45 second scroll operation, as compared with a workstation with a single 1Kx1K monitor and a 0.1 second scroll operation.

For our analysis we have developed a generic 40 slice CT chest study with 30 slices containing lung, 30 containing soft tissue, and 10 containing liver. When printed on 14"x17" film, the lung is on three sheets of film, the soft tissue is on three, and the liver on a single sheet. This generic study is the average of 20 randomly selected CT chest studies from UNC Hospitals.

In addition to a generic CT study, we also need a generic image interpretation scenario detailing the exact number of scroll and other operations a typical radiologist will follow while interpreting our generic single CT study. We assume the following generic scenario: First, the radiologists load the films onto the workstation or alternator (times for pre loaded alternator included). Second, they overview the entire study starting with the lung, then the soft tissue, and finally the liver. Third, they focus on two interesting anatomical areas (each area involved 10 slices). Fourth, they dictate the report again viewing these two areas. Fifth and finally, they unload the films and place them back into the patient's folder (film only). This generic scenario was developed from observation of 25 CT chest interpretations involving 8 different radiologists. Obviously there are hundreds of different ways to read a CT chest study and different scenarios could result in different estimates for image manipulation times.

3.2 Image Viewing Systems Modeled

We constructed GOMS time-motion models for nine different real and hypothetical CT viewing systems using the above generic CT study and generic CT interpretation scenarios.

System #1 was the UNC FilmPlane radiology workstation, configured using a single 1Kx1K monitor with a 1.5 second scroll. For a "down" scroll operation the bottom two 512x512 images were moved to the top of the monitor and two new images displayed in their place. Details of the workstations design and observer evaluations are given in previous papers^{4,5}. FilmPlane uses a navigation view pictorial index to allow the radiologist to randomly access any image in the patient folder without having to sequentially scroll through a CT study. Pictorial indexes are useful for workstations with small screens and slow response times.

Radiologists often need to move their eyes back and forth over six to eight CT images in order to form an understanding of the 3D anatomy visualized⁴. With only a single 1Kx1K monitor displaying only four 512x512 images at the same time, there is a considerable amount of back-and-forth scrolling while the radiologist tries to visualize the anatomy while focusing on interesting anatomical areas. Our generic CT interpretation scenario does not take this additional scrolling into account. Therefore it may somewhat underestimate the image manipulation for this configuration.

Due to the X windowing system, FilmPlane can be configured with any number of 1Kx1K monitors. However as the number of monitors increase, there are more images that must be displayed during a scroll, and therefore the system response time increases. *System #2* used two 1Kx1K monitors with a response time of 2 seconds.

Foley⁶ conducted an observer experiment analyzing a commercial workstation with two 1Kx1K monitors and either a 7.5 second response time with eight 512x512 images or a 26 second response time with 32 256x256 images. *System #3* models such a workstation by modifying the FilmPlane model with two screens and an 8 second scroll time.

System #4 models a fast and simple CT display system called FilmStrip II we have recently developed with one 2.5Kx2K monitor (a Megascan) and a 0.11 second scroll time⁷. Filmstrip uses a very simple mental model of a three-wide vertical strip of CT images. In practice, the radiologist uses "up" and "down" buttons to scroll through the study. "Lung", "softtissue," and "liver" preset buttons are provided for fixed intensity windowing. No provision is made for dynamic windowing; as with film, we assume that a technologist has pre-windowed the study. Since the radiologist can scroll from one end of the study to the other in only a few seconds, a navigation view or pictorial index is not necessary.

FilmStrip II is quite expensive with the hardware alone costing at least \$40,000 in 1992. As a low cost alternative, Brad Hemminger has developed *System #5* called FilmStriplet, which uses two 1Kx1K monitors attached to a Sun Sparc II workstation with 64-128MB of memory. FilmStriplet uses a horizontal FilmStrip mental model similar to FilmStrip II. Because we only provide fixed preset intensity windows, we are able to scroll the workstation in under 0.1 seconds.

Systems #6-#9 involve the use of film and a horizontal alternator. Few radiologists use the upper four fixed lightboxes with reading a single CT study, so we assume that only the bottom row of four lightboxes is available. Most radiologists place their seat between either lightbox #1 and #2, or #3 and #4 and can therefore only view two boxes without having to move their chair so we include systems #6 and #7 which use only 2 boxes, as well as systems #8 and #9 with four boxes. Since moving the chair to switch to the other two boxes takes about the same amount of time as scrolling the alternator, there is almost no difference between using all four boxes on the bottom panel and keeping only two boxes lit.

Some radiology departments have their technologists pre-load the alternator with the day's cases making it difficult to decide whether a speed comparison of radiology workstation and film interpretation times should include the time to take the films out of the patient folder and mount them on the alternator, and the time to take the films off the alternator and place them back into the patient's folder. This is an important consideration because timing studies (see section 3.X) show the load/unload operation to take about 70 seconds or roughly 23% of the film interpretation time for

a single ordered CT chest study placed as the sole study in a patient folder. Therefore, film-viewing *Systems #6-#9* have modeled film interpretation with both two and four box alternators and with and without film load/unload time.

3.3 Model Results

1 Tool	2 # Screens	3 Screen	4 Scroll	5 Image Manip- ulation	6 Estimated Interpret. Time	7 Actual Time
1) FilmPlane		1 1Kx1K	1.5 sec	2:23	7:36	8:02
2) FilmPlane		2 1Kx1K	2.1 sec	1:58	6:48	-
3) SlowFilmPlane		2 1Kx1K	7.5 sec	3:21	8:11	-
4) FilmStripII		1 2Kx2K	0.12sec	0:28	5:18	5:39
5) FilmStriplet		2 1Kx1K	0.1sec	0:48	5:38	-
6) Film/Altw/oLoadUnld	2	-	1 sec	0:16	5:06	-
7) Film/Altw LoadUnld	2	-	1 sec	1:26	6:16	-
8) Film/Altw/oLoadUnld	4	-	1 sec	0:09	4:59	5:01
9) Film/Altw LoadUnld	4	-	1 sec	1:19	6:09	6:13

Table 2
Single CT study image manipulation time estimates
for workstations and film with estimated interpretation
times and actual interpretation times where available.

Table 2 contains the GOMS time-motion analysis results for the various image viewing methods described in section 3.2. System response time in the fourth column is for the scroll operations described in 3.2. It is important to remember that the image manipulation time given in the fifth column is not the time for a complete interpretation. For example, the time to interpret a CT study on film with an alternator using four boxes not counting the time to load and unload the film (#8 in table 2) is actually about five minutes. The time motion analysis (backed up by observation sessions) indicate that only about 10 seconds of that time is actually spend manipulating the alternator; the other 4 minutes and 50 seconds is spent looking at the images, dictating the report, and manipulating the dictation machine. If we make the very rough assumption that the same amount of time will be spent viewing images with an electronic workstation as with film and an alternator, we can add four minutes and 50 seconds to each of the image manipulation times given in table four column five and generate the estimated interpretation time given in column six.

In order to be able to judge the accuracy of the modeling data, column seven contains average interpretation times for those image viewing systems with available observer studies^{4,5,7}. Generally, the modeled times are roughly within 30 seconds of the ac-

tual times. While the slowFilmPlane (system #3) is similar to the Foley workstation⁶, it cannot be compared easily because Foley's workstation allowed the user to view either 8 512x512 images with a 7.5 second scroll or 32 256x256 images with a 24 second scroll and we do not know how often the radiologists chose each viewing method.

3.4 Discussion

It is important to understand the relationship between screen space (the number of CT images that can be simultaneously displayed) and system response time for a scroll operation. The more images that are displayed simultaneously, the fewer the number of scroll operations that will be necessary, but the more information that must be moved across the workstation's bus and into the various framebuffers, increasing the time for a scroll operation. Since there is a limit to the number of monitors radiologists can actually use without having to move their chairs, there comes a point after say three or so monitors, where it would be better to develop a faster system response time than to add additional monitors.

In the case of FilmPlane, having two monitors is clearly better because eyetracker studies⁴ indicate that radiologists often view clusters of six or more CT images; a single 1Kx1K monitor containing only four full-resolution CT images would require the radiologist to scroll back and forth to visualize a cluster, greatly increasing the number of scroll operations. On the other hand, adding a third monitor to FilmPlane would be counterproductive because two monitors can already show eight full resolution images (more images than in most clusters noted during the eyetracker study) the increase in system response time would not be offset by the additional screen space, and the third monitor would require radiologists to move their chairs.

The estimated interpretation times of systems #4 and #5 are of particular interest. We conducted an observer study⁷ in which four radiologists interpreted 10 single CT chest studies using film/alternator and FilmStrip II (system #4) with a single 2Kx2K monitor. As table 2 column 7 shows (systems #4, #8, and #9), the interpretation times for FilmStrip were about 30 seconds faster than film/alternator if load and unload time are included, and about 40 seconds slower if load and unload are ignored. Further, there was no detectable difference in interpretation accuracy of all dictated reports from both systems, and radiologists were confident in the image manipulation with the workstation and in the quality of their dictated reports. FilmStrip would make an acceptable CT workstation for primary interpretation of single studies. Unfortunately, FilmStrip requires \$40,000 in hardware, let alone software and marketing costs.

However, FilmStriplet's interpretation time estimate is almost the same as FilmStrip and FilmStriplet can be constructed with a \$15,000 commodity priced workstation containing 64MB - 128 MB of main memory and a 1Kx1K monitor. While we have not conducted formal observer studies of FilmStriplet, preliminary

observation indicates that a two screen FilmStriplet with two 1Kx1K monitors and 0.1 second scroll times has promise as a viable single CT interpretation system.

FilmStriplet does not facilitate dynamic intensity windowing, because such operations can not be performed quickly with 8-bit framebuffers and 12-bit image data. However the lack of dynamic intensity windowing may be an advantage; when using a radiology workstation, radiologists have a tendency to spend a lot of time (over 10 seconds per window setting) locating the perfect intensity window, while they almost always accept the intensity window the technologists set when a CT image was printed on film. We suspect that it will be more efficient for the technologist to continue to preset the intensity windows even if the radiologist plans to read from softcopy.

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Comparison of Film and Screen Interpretations of Subtle Orthopaedic Fractures

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INTRODUCTION:

Teleradiology is becoming increasingly popular as a means of providing "wet readings" for radiologic examinations when a radiologist is not available at the examination site. We have been interested in providing night-time radiology coverage for the emergency room of a nearby hospital. Previous studies at our institution showed some loss of accuracy when comparing teleradiology interpretation to film interpretation.⁽¹⁾ Failure to identify fractures in the emergency room situation is always a concern. Studies using digitized film images have shown difficulty in the identification of non-displaced fractures at pixel sizes greater than 0.16 mm.⁽²⁾ A study by Wegryn et al⁽³⁾ indicated that slightly less stringent resolution requirements were satisfactory. Our interhospital teleradiology system employs 0.2 mm. pixel size. The current study measures the performance of this system in the detection of subtle fractures and other post traumatic changes. This study evaluates the "worst case" scenario in the application of teleradiology to diagnosis of trauma cases. No prior study has tested a teleradiology system with very difficult trauma cases. These are the very cases no one wants to "miss". They are the type of case for which emergency medicine staff might well desire radiologic consultation.

MATERIALS & METHODS

The Teleradiology System:

The system links two hospitals, Francis Scott Key (FSK) and The Johns Hopkins Hospital (JHH) (Figure 1). A user interface at the transmission site allows for keyboard entry of clinical and technical information by a clerk or technician in roughly one minute. This information is attached to the digitized image data in the form of a header.

Next, the conventional analog films are laser-digitized by a clerk or technician. Prior to the study, the laser-digitizer was tested by the manufacturer for linearity, uniformity, modulation transfer function, and noise characteristics. Conventional radiographs were digitized at 210

microns spot size (0.2-mm pixel), 12 bits contrast resolution and 2.35 line pairs per millimeter spatial resolution. A 14 x 17-inch chest film is digitized in 12 seconds, producing 6 MBytes of digital image data. The resultant images are 1,680 x 2,048 pixels and are interpolated down to the display memory size which is 1,280 x 1,024 pixels. Once all films in a given exam are digitized, the image data are transferred into a medical imaging gateway (MIG) and acknowledged. This MIG contains 300 MBytes of temporary magnetic storage. Acknowledgement takes approximately 45 seconds.

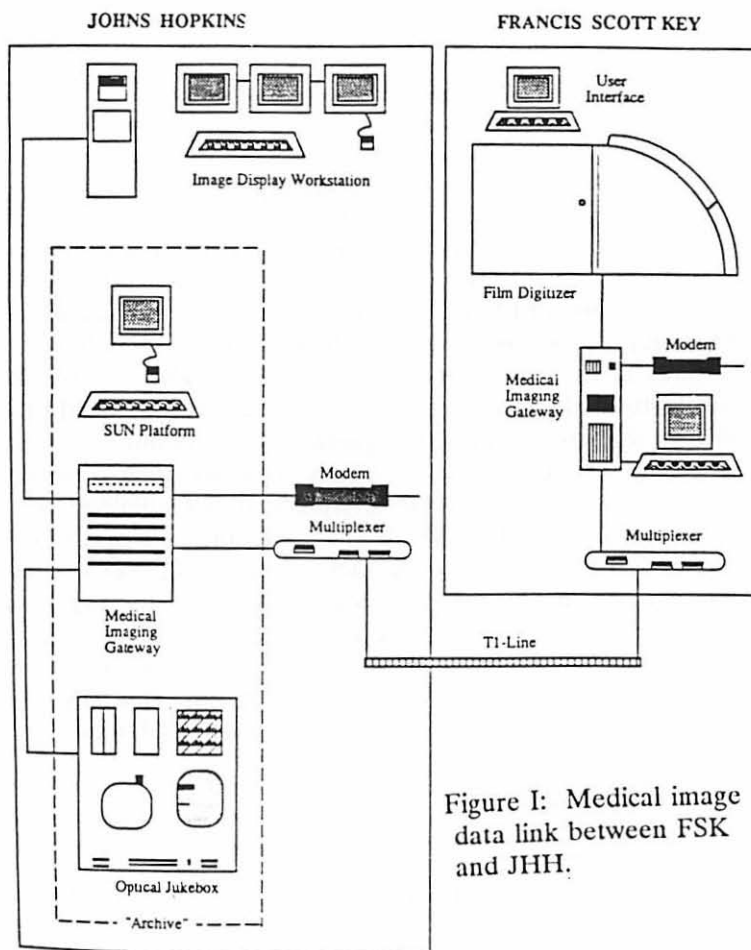


Figure I: Medical image data link between FSK and JHH.

The image data and header information are transmitted from FSK to JHH over a T1-line. The transmission rate of 1.544 Mbits/sec results in approximately 30 seconds to send a 14 x 17-inch film. The image data are then received and acknowledged by a MIG at JHH with 300 MBytes of temporary magnetic storage. Images automatically migrate later to an

optical jukebox for permanent storage. Image data can be compressed at a ratio of approximately 3:1 to reduce required storage space using a *non-destructive algorithm*. The jukebox has a 12.4 GByte capacity and contains two optical disk drives to facilitate data access. A SUN platform manages system traffic.

The system coordinator can issue the command to send one or more patient examinations to a local storage unit which supports the image display monitors. The local storage device has a 280 MByte capacity capable of storing 35 to 40 digitized images. All images are loaded prior to the radiologists' workstation reading sessions. The Random Access Memory (RAM) that supports each of two monitors has 8 MBytes of image memory, enough to accommodate a single chest image for each screen.

The patient examinations available in local storage are listed on a text display monitor and may be selected for display by using a computer mouse. Each digitized film takes roughly 8 seconds to display. They are viewed on two image display monitors (1280 X 1024 pixel elements, 8-bit depth display). The patient demographic information extracted from the image header, in addition to the image manipulation function menu, are shown on the text monitor. The available image manipulation functions include zoom (2 and 4 times), pan or roam, *window* or contrast manipulation (over the full 12-bit depth), *level* or brightness manipulation, reverse polarity (black bone), and a ruler to measure straight line segments. The original image data are displayed in full resolution when the image is zoomed to a 2:1 ratio. The selection of each function is controlled interactively by a mouse.

Case Selection:

Cases for interpretation were selected from clinical practice at The Johns Hopkins Hospital. Sixty cases with subtle fractures or dislocations and 60 cases of similar age and with typical age-related degenerative changes but without fracture or dislocation were available on the original radiographs for this study.

The difficulty of the cases was determined by two of the authors who did not participate as readers (Table 1). They also selected the particular abnormality (fracture or dislocation) to be identified in each case. Cases "missed" by three or more of the eight readers were reviewed by a consensus panel to determine that in fact the abnormality was present.

TABLE 1
Study Case Difficulty

Case Difficulty	Study Cases	
	#	%
Low	37	30.8
Moderate	54	45.0
High	29	24.2

Interpreters:

Seven senior radiology residents and one fellow served as the interpreters. Each read 60 cases on original films and 60 cases on the monitors of the teleradiology system. The order of cases was randomized and no case was presented to any one reader both on film and screen. The only history provided to the readers was one of "motor vehicle accident" in all cases. Interpreters gave confidence ratings of low, moderate, or high for their diagnoses and judged the technical quality of the images.

Post Study Questionnaire:

Following completion of the trial, each of the interpreters completed a questionnaire regarding aspects of study design and equipment characteristics which might have influenced their interpretations.

RESULTS:

The accuracy, sensitivity and specificity for film and digital interpretations for all interpreters combined are shown in Table 2.

TABLE 2
Interpreter performance by Mode

Measure	Mode		
	Analog	Digital	Overall
Accuracy (%)	80.6	59.8	70.1
Sensitivity (%)	78.8	48.8	63.6
Specificity (%)	82.8	72.7	77.8

Table 3 shows the distribution of technical quality assigned to the images by the interpreters.

TABLE 3
Interpreter's Perception of Technical Image Quality by Mode
Based upon readings

Technical Image Quality	Analog		Digital	
	Readings	%	Readings	%
Technically Limited	84.0	17.5	148.0	30.8
Adequate	197.0	41.0	231.0	48.1
Good	199.0	41.5	101.0	21.0

Table 4 relates interpreter performance to technical image quality and mode.

TABLE 4
Interpreter Performance by Technical Quality and Mode

Measure	Technically Limited		Adequate		Good	
	Analog	Digital	Analog	Digital	Analog	Digital
Accuracy (%)	73.8	47.3	81.2	65.4	82.9	65.3
Sensitivity (%)	68.2	31.4	78.9	56.3	82.9	60.0
Specificity (%)	80.0	69.4	83.9	75.0	82.9	71.7

Table 5 relates interpreter performance to difficulty and mode.

TABLE 5
Interpreter Performance by Difficulty and Mode

Measure	Low		Moderate		High	
	Analog	Digital	Analog	Digital	Analog	Digital
Accuracy (%)	83.8	75.7	83.3	61.6	71.5	36.2
Sensitivity (%)	81.7	70.8	83.0	50.0	71.6	29.5
Specificity (%)	85.7	80.3	83.6	71.6	71.4	57.1

Table 6 relates interpreter performance to confidence rating.

TABLE 6
Interpreter Performance by Confidence and Mode

Measure	Confidence Rating					
	Low		Moderate		High	
	Analog	Digital	Analog	Digital	Analog	Digital
Accuracy (%)	60.0	47.8	81.1	57.2	86.1	68.9
Sensitivity (%)	83.3	50.0	72.5	28.9	81.1	65.2
Specificity (%)	31.0	45.5	87.6	82.0	94.2	75.4

The completed questionnaires indicated that the majority of the interpreters were satisfied with the image quality, spatial resolution, and brightness of the digital display system, reporting them as adequate to good. There were, however, several concerns/complaints regarding the current system.

The image manipulation panel setup was felt by all the interpreters to be poor. Adjusting the images to the proper window settings was "cumbersome" and "time consuming." Also, the time that it took to call up the digital images on the screen was "too long" according to all the readers. The physical environment was also felt to be a problem. The digital screens were "sensitive to glare" from background lighting; it was "difficult to set the lighting properly for optimum reading."

All but one of the interpreters felt their accuracy of interpretation was less for the digital images than for the standard films. Most felt this decreased accuracy was at least in part due to the above stated problems

with the present system. Not surprisingly, suggested improvements included increasing the ease and speed of image manipulation and significantly decreasing the image display time. Also, everyone suggested placing the digital screen display system in an isolated environment to eliminate glare and other distractions.

DISCUSSION:

A recent study by Carey et al⁽⁴⁾ concluded that a teleradiology system with resolution similar to that employed in the current study, but using laser-digitized films for interpretation provided sufficient accuracy for final diagnosis. Our own previous study of chest and bone cases (1) led us to believe this was not the case and that significant diagnostic inaccuracies would result. The results of the current study support our previous findings. Accuracy for analog film interpretation was 80.6% versus 59.8% for digital interpretation. This represents a significant difference in the two modes.

The work of Wegryn⁽³⁾ and Murphey⁽²⁾ indicates that the system resolution employed in the current trial is borderline for diagnostic interpretation of subtle fracture cases. The study bears this out.

The case mix in our study was strongly and intentionally skewed toward more difficult than average fracture cases. This dramatically accentuates possible failings of a teleradiology system. While this is definitely not the average mix of cases encountered in daily emergency room practice, it represents the cases for which consultation might be requested and most desired by our emergency medicine colleagues. Only a few "missed" cases can lead to significant health consequences for the patients and financial consequences for the health care provider.

Probably a higher degree of spatial resolution is required than provided by the system which we utilized. Results of the questionnaire completed by the interpreters following the study indicate that improvements in response time, viewing station surroundings, and ease of image manipulation are likely to considerably improve results for digital interpretation. We plan further studies incorporating such improvements.

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Design and Implementation of a Visualisation Tool for Radiology

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I. Introduction

A radiological institute has a number of image producing devices at its disposal. Recent developments in digital image processing techniques have enabled ever better and more accurate diagnoses to be made¹. It has been necessary to develop an interface that can support the tasks involved in managing the large amounts of data associated with such images and techniques. In particular, an interface is needed which facilitates the storage of this data as well as its retrieval and processing at some later time^{2,3,4}.

A primary design goal in developing this interface is that the ever growing number of ever more efficient algorithms for manipulating and analysing radiological images should not, in end effect, cause difficulties for, or even hinder, the radiologist in his or her work. The appearance of departmental super computers has enabled not only the storage of this data, but also its processing at the speeds required in order to be of use to the clinician.

II. Material and Methods

The interface was developed using a CONVEX C220 super computer with 128 MB of main memory and 16 GB as basis. The salient features of this computer are its large memory and extremely high disk access speed (up to 60 MB-sec), which combined enable data in memory to be quickly processed. X-terminals with a color depth of 8 bits (mapped to 256 shades of grey) were used as the output devices for a initial step. In the first phase of development, it was not necessary to be able to produce color output. However, this will be imperative for implementing contour searching algorithms and 3D reconstructions^{5,6}.

The connection between output devices and the CONVEX was made over a 10 Mbit network. In the future a FDDI network will bring a speedup, so that the network performance is not the factor of limit.

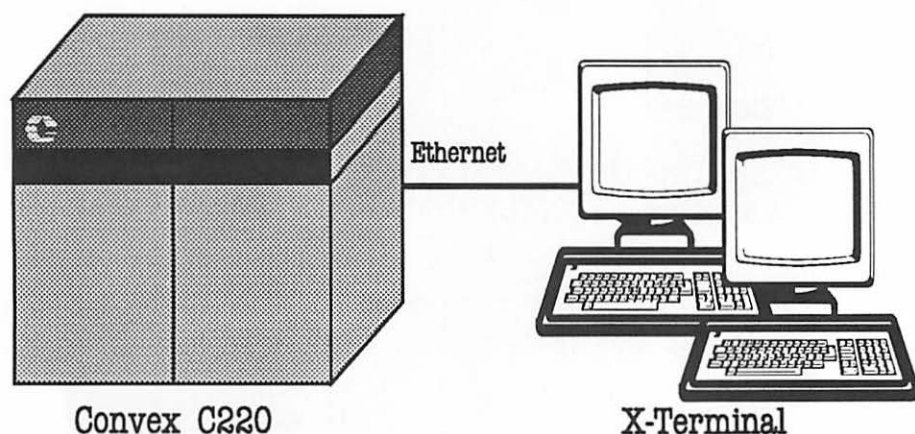


Figure 1: Development Configuration

From the software side of things, the system was required to run on as many different kinds of hardware platform as possible. To this end, UNIX was selected as the operating system and 'C' as the programming language. After much searching, a graphic system consisting of the X Window system from Massachusetts Institute of Technology (MIT) and the OSF (Open Software Foundation) Motif Toolkit crystallised. A main consideration was that the basic Toolkit should be suitable for use on practically all workstations and popular super computers. The medical data was stored in ACR-NEMA format, which provided for a high degree of compatibility with the devices which produced the data.

III. Results

Our main goal was to produce an interface which was simple to maintain, simple to learn, and which would spare the user any direct 'confrontation' with UNIX or the system at the programming level. In order to meet the requirements of the radiologists, it was necessary to provide a working area of 1024 x 1024 pixels. Therefore, the interface is divided into three areas: the working area, the menu field and the information field (figure 2).

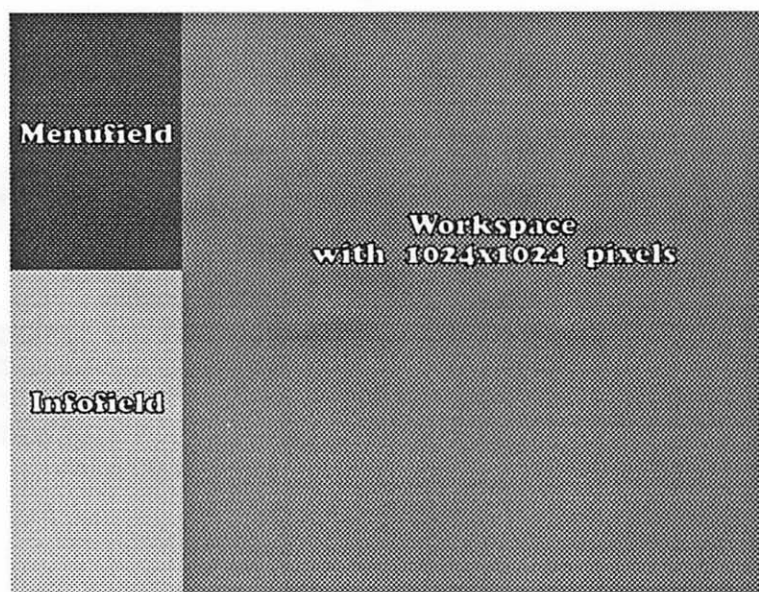


Figure 2: Surface design

The working area, which constitutes the largest of the three areas, is used for displaying and processing images. Since our initial efforts were primarily concerned with processing CT scans, the following remarks pertain to this kind of radiological image. The display can be made with three different levels of resolution:

- 1024x1024 (~ 1 scan)
- 512x512 (~ 4 scans)
- 256x256 (~ 16 scans)

In addition, it is also possible to select an overview display with which 64 images, each having a resolution of 128 x 128, can be output. Each of these component images can be selected and displayed in its original size. It is, of course, possible to scroll through the entire sequence of images at any time. All information regarding the images is also displayed in the working area; image output is automatically directed to this part of the screen. When the images are displayed in their original resolution, image related data is displayed as an overlay over the image. Such data might include, for example, the table position or the

cross-section number. One might also choose to display the original Houndfield units at each point in the cross-section.

The menu field is further subdivided into three regions. In the first of these regions, information such as the version number of the program, the clinic name, and the name of the clinician who is currently logged in on the system are displayed. In addition, the current date and information regarding the status of the system appear here. The second region contains a menu bar which provides the following pop up menus:

- System (Quit, Configure ..)
- Images (Image manipulation, Rotate, Segment, ...)
- Sessions (New login, Talk with other user ...)
- File (Load, Store, Combine ...)
- Contact (HIS, RIS, E-mail ...)
- Terminal (Login on another station)

These six functional divisions were considered to be essential. In selecting these functions, we have already foreseen the requirements arising from such new concepts as communication with a radiology information system (RIS) or a hospital information system (HIS). The most important functionality is, of course, image processing with its various algorithms for image post-processing and enhancement, as well as its segmentation algorithms and Sobel and Laplace operators. Via selection of individual images, it is possible to reduce a large sequence of CT or MR images to a few crucial ones. These menus can be extended at any time, thus facilitating integration of new functionalities in the system.

The third region will contain buttons with which the clinician can quickly execute functions which are frequently used. All button functions can also be found in the menus. Conversely, any menu option can be assigned to a button.

The information field provides the user with the most important information regarding the patient or the currently selection function. In addition, those parameters which are necessary for executing the function are displayed here and can be changed as needed by the clinician.

Included is also an intelligent patient browser which can easily handle different examinations for one patient and support the physician by choosing the correct study. The design determine four types of folders. One for patients which examination was taken today, one for yesterday, one for the day before yesterday and at least one for all of the patients. The studies, on the other side, are also saved into a tree of folders. However, this kind of data hierarchy was chosen to handle a big stack of patients and have also the opportunity to delete or store a completed patient on another media.

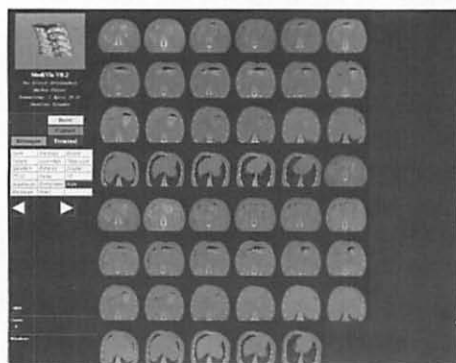


Image 1

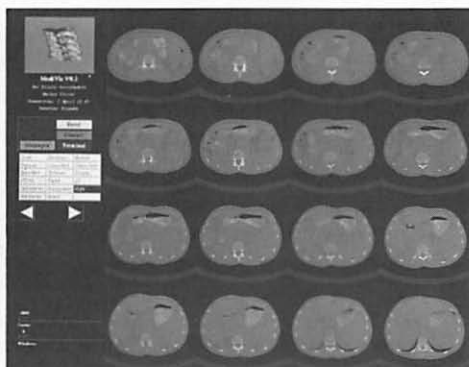


Image 2



Image 3

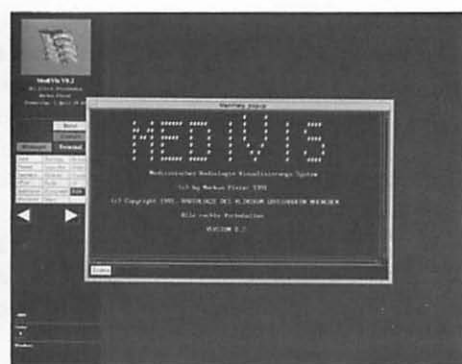


Image 4



Image 5

- Image 1: A CT sequence to select the important images
 Image 2: Overview of the CT sequence
 Image 3: The original images
 Image 4: The help function
 Image 5: The patient browser

IV. Conclusion

The system presented here is to serve as a user interface to a picture and archiving system (PACS)^{7,8}. Therefore, it has been necessary to define interfaces appropriate for a PACS. The effort involved in realizing these interfaces was reduced considerably by choosing the ACR-NEMA standard as the basic image format. Unfortunately, it has not yet been possible to test our system with one of the PAC systems available on the market. The time required to load or manipulate an image is highly dependent on the basic hardware used. The use of algorithms for quickly displaying image sequences and pre-fetching images is planned for the future. Once such algorithms are implemented, image transfer over the network will represent the greater part of the time required for image display. Because of the great quantities of image data to be found in a radiological clinic, the presentation of image sequences on the local workstation, which is the only way to ensure sufficient processing speed, is possible only to a limited degree.

High performance workstations are certainly capable of having several gigabytes of data at the ready for the clinician. However, in so far as the radiological analysis is performed digitally, this capacity appears quite small.

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Early Experiences With X Window Imaging Extensions (XIE)

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INTRODUCTION

X is a windowing system that provides a familiar point and click interface to user applications. However, it is distinguished from other popular windowing systems (such as that on the Macintosh and "Windows" on the IBM PC) in that it has as its goals *network transparency* and *vendor independence* [1]. X is network transparent, in that applications that produce results need not run on the computer that supports the display device for the display of those results. X distinguishes between client programs, which accept input and produce results, and server programs, which interact with the user through the mouse, keyboard and display. While client and server can and frequently do reside on the same machine, they are not constrained to do so. A special class of devices have evolved, denoted X-terminals, which incorporates the X server program. These are typically diskless devices capable of displaying output from several client programs at once, with the client programs running on different remote machines. Thus, on the same display device, clinical information for a patient originating from one machine can be displayed along with images for that same patient originating on a different machine [2]. Secondly, because X is a well defined standard, it provides for true vendor independence. Any client program conforming to the standard can interact with a user at an X server, providing the client program conforms to the "visual class" of the server (e.g., bitonal, grayscale or color). X-terminal vendors compete with one another to provide performance at a low price, all the while providing products that are interchangeable without requiring rewrites of client programs. Nonetheless, while providing low-cost capability for a broad class of applications, X display devices have suffered by comparison to special-purpose, proprie-

tary displays for medical imaging. A frequent complaint is that X is too slow, or that it does not provide the functionality necessary to support medical imaging applications. While there is validity to these criticisms, X has proven to be of great utility at specific locations in our institution where limited imaging functionality is required [3]. Furthermore, two recent developments have combined to ameliorate the insufficiency of X for a larger array of medical imaging applications.

The first of these is the introduction of RISC (Reduced Instruction Set Computer) technology to X-terminals. Several vendors currently market RISC implementations to execute the X-server program, with enormous improvements in speed and performance. The second development is the focus of this paper: The emerging Imaging Extensions to X, or XIE [4]. Extensions to X are fully sanctioned additions to the core X protocol, which is under the control of the MIT X Consortium [5]. As such, they can be incorporated into servers from a variety of vendors and provide functionality not addressed in the core X protocol. XIE draft version 4 [6] is currently before the X Consortium for review, where consensus appears to have been reached and acceptance is likely to be a few months away. XIE provides several features which are of potential utility to the medical imaging community, four of which will be discussed in this paper: support for 12-bit imaging, independent image windowing capability, zoom, and support for compression/decompression.

MATERIALS AND METHODS

A demonstration client program was written for a DECstation 5000/200 running the Ultrix 4.2A operating system, using XIE client libraries provided by Digital Equipment Corporation. The X-terminal used for this evaluation was an NCD19g, which is a Motorola 88100-based grayscale display provided by Network Computing Devices, Inc. The XIE server program for the 19g was provided by Congruent Corporation, and conforms to draft version 3 of the XIE protocol specification.

The demonstration program presents a side-by-side comparison of imaging capability using XIE versus X without extensions. Each of the

four important medical imaging features mentioned above were evaluated using this framework.

DISCUSSION

Support For 12-bit Imaging

Most display devices provide 8-bit frame buffers for grayscale imaging. 8 bits is a good match for the luminance of typical monochrome monitors. However, most medical imaging modalities produce images with pixel values in the range of 10-12 bits. Consequently, in order to view all the features that are present in an image, it is necessary to "window" through the image, or remap up to 12 bits into 8 bits for viewing of a particular feature. Ideally, this remapping process should be dynamic, tracking a remap request interactively and responsively.

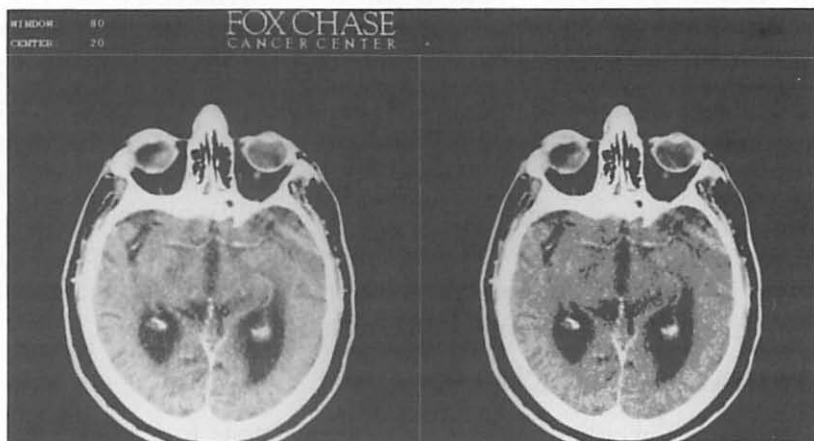


Figure 1

This presents a problem for X-terminals, where the server (display) is remote to the client (display program). X supports two classes of "drawables": pixmaps, which are never visible on the screen, and windows, which are. While pixmaps can be used to backload images from a study for subsequent viewing, they are constrained by the X model to match the depth of a window, which is typically 8 bits. Consequently, a conventional X-terminal cannot accommodate a 12 bit image. The 12-to-8 bit mapping must be performed by the remote client, and must be done each time a new view is required. If fluctuations in

the window settings are small, an 8 bit image can be loaded into the X-terminal with sufficient latitude to permit good results, and X will permit dynamic modifications to the presentation of the image through lookup table adjustments. However, large changes can produce disastrous results, as shown in the right image of Fig. 1. This image suffers from severe truncation artifact. The alternative is to retransmit the image over the network to the X-terminal every time large fluctuations in window settings are made. If the host computer is serving multiple X-terminals and is constrained by memory limitations, this may entail rereading the image file from disk. This is hardly a dynamic, responsive approach.

XIE addresses this problem by introducing a new structure, the photomap. Photomaps need not match the depth of X drawables, and can be up to 16 bits deep. An export function is provided that maps the photomap into a drawable of lesser depth via a lookup table. On the NCD19g, this process occurs rapidly, tracking remap requests on demand for 512x512x12 images. The image displayed on the left in Fig. 1 is generated from a 12 bit photomap, stored entirely within the X terminal.

Independent Image Windowing

As mentioned above, X permits dynamic changes to image presentation, but only through lookup table adjustments, where the lookup table is downstream to the frame buffer. Consequently, a change to any image on a conventional X-terminal produces changes to *every* image displayed, an undesirable result. XIE supports changes in image presentation by remapping every pixel in an image, holding the lookup table constant. This approach thus permits changes to a single image, while the presentation of other images on the same display is unaffected. The left image in Fig. 2 is an XIE remapped presentation of the same image shown under X on the right, which is unaffected by the dynamic remapping.

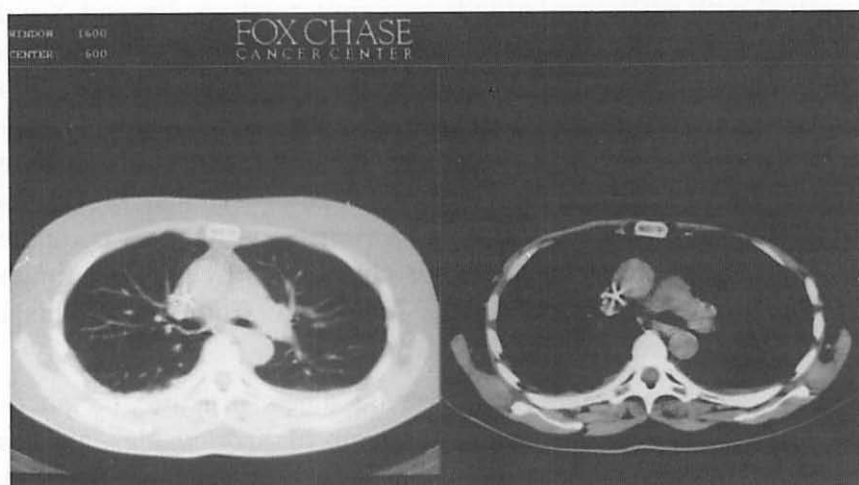


Figure 2

Zoom

There is no provision in X for the scaling of images within the server. XIE does provide support for scaling, however, our implementation of an XIE server is Version 3 compliant, and V3 of the XIE specification does not make provision for different sampling techniques. The baseline method chosen for the server we used is a nearest neighbor method, which is unsatisfactory for medical imaging, as demonstrated in Fig. 3.



Figure 3

The image on the right is a scaled version of the region of interest outlined on the image on the left. Version 4 of the XIE specification supports two additional techniques, bilinear interpolation and gaussian, which will provide the quality needed for zoomed medical images. While zooming with a nearest neighbor technique is fully interactive with the equipment we tested, it is unclear how responsive a more compute-intensive algorithm would be.

Compression/Decompression

Again, X makes no provision for the handling of compressed data. The XIE specification calls for the inclusion of JPEG (Joint Photographic Experts Group) compression, which proposes codecs for 12 bit images, for both lossy and lossless modes [7]. JPEG, excepting the compliance specification, is in the final balloting process (ballots are due by July 2, 1992) with acceptance anticipated. The implementation of JPEG in the XIE server we tested provides for 8 bit discrete cosine transform compression (DCT) only. In Fig. 4, the image on the left is a compressed form of the image on the right, with a compression ratio of approximately 3:1.

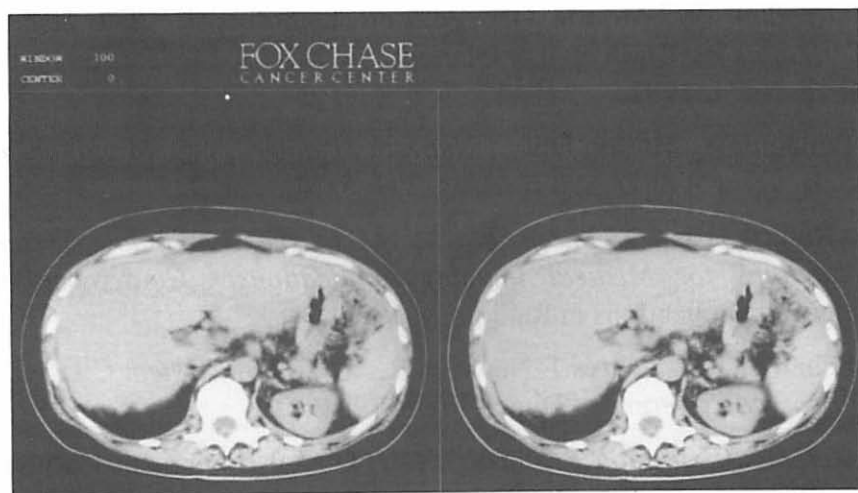


Figure 4

CONCLUSIONS

XIE, combined with newer RISC-based X-terminal technology, appears to provide substantial functionality required by the medical imaging community that is lacking in the X standard alone. This will be particularly true if the JPEG and XIE standards, as proposed, soon gain their anticipated acceptance as standards. This will mean lower cost display stations for the viewing of medical images, with a protection of one's software investment as newer devices with improved performance become available that conform to these standards.

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Design of Useful and Inexpensive Radiology Workstations

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1. INTRODUCTION

In order to fully achieve the advantages associated with a radiology Picture Archiving and Communications Systems (PACS), it is crucial to have a digital display medium. A significant amount of effort has been spent developing electronic versions of the film/lightbox combination. While we have seen large numbers of workstation designs produced and described, very few are actually in service in the clinic at this time. The few situations where electronic workstations are reported in use today are mostly in ICU locations where CR is involved, the images to be seen are few, and very high resolution is not required.

Why have we not seen a proliferation of electronic workstations? Three major reasons are (1) connectivity, (2) ease of use, and (3) cost. Without connectivity to provide easy and convenient access to remote image and patient data, the workstation by itself is useless. Connectivity is an issue for PACS design, however, and will not be addressed in this paper. The ease of use and cost of a workstation for reading patient studies is a part of the design and implementation of a good workstation console, and are the focus of this paper.

First, I suggest some guidelines for designing Radiology PACS consoles and examine how existing workstations follow these guidelines. Then I will describe a classification dividing the image display problem into two categories, and cover how the design guidelines apply to each of the categories. At the same time I will detail our experience implementing two such designs on several hardware architectures. Finally, I will discuss results from our studies comparing readings done using these implementations versus readings on film and lightboxes or alternators.

2. Background

While there are many good rules and guidelines for designing PACS console applications, I have focussed on four guidelines that I consider to be the most crucial and the most often disregarded. These guidelines are well documented in Computer Human Interaction (CHI) literature; however, many existing workstations designs seem to have ignored them.

2.1 Build the tool for the task

Prior to designing any tool, the task should be well understood. The tool should be built for that task. Only a few applications, for instance the AVC for chest films [1], and FilmPlane for chest CT [2], have studied a problem and then designed a tool for that situation. Additionally, it is a good idea to incorporate prior information about the patient study to choose the specific tool or version of a tool to be used for displaying the images [3].

Most existing workstation applications are not focused on a task. By far the most common theme is to choose either a tiled or overlapping arrangement of images and then associate with the images a grab bag of operators on the images. While one of the advantages of digital workstations is the ability to apply many different operations to an image, this does not imply that the designer should include any and all operations in their application.

2.2 Simple, easily understood mental model

For the user to be comfortable and efficient using the tool, it must be natural for them to use. This will only occur if they have a simple mental model of what the tool is and what it does. It is desirable to make use of analogies to tools that users are already familiar with, for instance, a desktop metaphor.

Most applications choose a two dimensional surface as their metaphor, allowing images to be placed on the surface following either a tiled or overlapping structure. While on the surface many of metaphors seem tidy, they often have problems. One example is when using a desktop metaphor of overlapping papers where each paper represents one image from a study. In our experience, this results in a confusing scene after the user moves several images around, resulting in a lack of sense of the patient study or where to find specific images. As another example, we found that the users had a much better sense of the study if we constrained them to a fixed format tiled presentation. However, in doing this we found it more difficult to present a consistent mental model when allowing operations like zooming and window and level (W/L) on individual images.

In some cases we have found it desirable to remove features (e.g. zooming) which, if removed, allowed the mental model to remain consistent.

2.3 Very simple user interface

Just like a hammer and nail, the interface should be invisible. If the user has a mental pause between actions while trying to determine how to do something, the interface is not transparent. This means it is hampering the user from accomplishing his task. This will frustrate him as well as slow him down. Again, from CHI experience it is generally recommended to determine the task, then design a tool for that task, then prototype a tool for the task, and then iterate through many prototypes with real users before settling on a final version.

Many existing interfaces are designed as a display area with a collection of associated image operations hidden in pulldown menus or on a dedicated menu area. There are many examples of applications where the unrelated image operations seem randomly stuffed into pulldown menubars. No consideration is given to what the task steps will be and how the user can most efficiently accomplish them. For instance in an earlier version of our first display console for CT [4] there were three screens (one

overall view of all the images minified to fit on one screen, and two full resolution working views). The interaction for choosing new images to appear on the working screens was to click either the *forward* button or the *backward* button on the mouse, or to point to the desired image on the overall view. We later discovered from observation and eye tracking experiments that the radiologists most common operation was to move linearly through the study and to look at up to 6-8 images at a time [5]. Since we could hold 4 images on each of the two working screens, we found that the radiologists preferred mode of interaction was to look at 8 images and then to scroll to the next 8 images. Unluckily, our interaction required them to do two separate scroll operations, one for each screen to accomplish this. This required clicking on one screen, then moving the mouse cursor to the second screen and clicking there.

It is often useful to model the task in order to design an efficient implementation. Some common modeling techniques we have used with success are the keystroke model [6] and the GOMS model [7]. For example in chest CT readings we found that by far the most common operation was to scan linearly through the images. This resulted in all of our recent workstation designs for chest CT (FilmPlane, Filmstrip) having the scroll operation be the easiest and quickest operation for the user to perform (either a mouse click or a dedicated oversized function key). Additionally, the operation was enhanced so that scrolls could affect multiple screens if the user was using these screens to provide a larger contiguous view into the study.

2.4 Interactions must be instantaneous

Probably the most common complaint observed with our earlier attempts was that it took too long. Radiologists are highly skilled and find waiting on a slow computer very irritating. Additionally, because they are highly skilled they are highly paid and with the current medical reimbursement situation most radiologists are in a sense paid by the piece. Thus time wasted waiting on the computer to act is a strong disadvantage to an electronic system's acceptance, both by the radiologist and the business manager.

Where thorough studies have examined speed and accuracy issues comparing film lightboxes with electronic workstations, the results have shown that electronic workstations are slower than lightboxes. Foley found that for body CT readings the four radiologists in the study were 33% slower on average when reading from two 1024x1024 image workstations [8]. He found that the major component of the increased analysis time was for screen changes (which required either 7.2 seconds when displaying 512x512 images, or 26 seconds for 256x256 images) [8]. Similarly, Beard found chest CT readings with FilmPlane to be slower than on film when readings were done on one 1000x1000 screen [9]. Additionally, he found that the difference in times between workstation and lightbox readings correlated with the amount of time the workstation spent doing scroll operations during a reading. Thus, if scroll operations occurred instantaneously we could expect the workstation to have a reading time comparable to that of the lightbox. This makes sense, as we know that the equivalent of a scroll operation on a lightbox is a glance, which takes a small fraction of a second.

As a result, I now use the rule of thumb that if an operation is not *instantaneous* it is not acceptable, regardless. This means that if I cannot find a way to implement scroll operations, zoom operations, W/L, image processing operations, etc. at the push of the button, they do not get included.

3. Design and Implementation

Of the four guidelines from the last section, building the tool for the task is the most important. While building the perfect tool might mean carrying this to the limit and building a tool for every clinical task, it is likely that there is enough overlap that a single tool can be used for several types of clinical situations. Our experience with chest CT and more recently with MR, standard chest Xrays and mammography has led me to generalize two types of display methods that fit most clinical situations. I will give some background reasoning for the classification split and then describe current designs that meet these guidelines and that can be implemented on hardware costing less than \$10,000.

Enough Screen Space?

The most limiting factor in designing electronic versions of lightboxes is the lack of screen space. A light box, or alternator in a common 4 over 2 configuration can hold 8 films, each which potentially represents 4000 by 4000 pixels or more. This means the light box has the equivalent resolution of 16000 by 8000, while today's highest resolution monitor is 2048 by 2560. (I will not go into luminance or contrast differences in this paper). This means the lightbox can display 25.6 times more material than we can show on a single monitor. We can certainly use multiple monitors if we are willing to live with border problems between monitors, but even with 8 monitors as some commercial manufacturers have prototyped, we still have less than a third of the resolution of the lightbox.

This means that one of the most crucial aspects of a display workstation is how it handles the issue of being able to display only a portion of a study at one time. This has also led me to segregate display programs into two groups.

sufficient screen space: Display applications that can display the *required* amount of information on the available screen space at one time.

insufficient screen space: Display applications that cannot display a necessary required amount of information at once.

This is more complex than just looking at image size. It requires knowing the task and what is required to accomplish the task. For instance, in single study chest CT we found that 6-8 images may be required to be visible at one time. Less than this number caused the radiologists to have to mentally remember adjacent images. In one study we constrained radiologists to use a single 1000x1000 resolution screen when using FilmPlane. This means they could only look at four 512x512 full resolution CT images at one time. When compared with their performance reading similar images in another study where FilmPlane was configured with 2 1000x1000 screens (thus allowing 8 images to be viewed at once) we found that they took more time to complete readings with the single screen and that they resorted to mental aids like writing down findings instead of remembering them, thus indicating more short term memory overload [9].

Thus, for single study chest CTs we have chosen the threshold to be the ability to display 8 512x512 images at once. If the display system can display 8 or more CTs at full resolution at once it is considered screen space sufficient, else it would be considered screen space insufficient. I make this distinction because I believe that different display paradigms should be used for screen space sufficient as opposed to screen space insufficient situations.

3.1 Screen space sufficient methods

For situations with sufficient screen space we use what we have termed a "Filmstrip" orientation. The mental model is a film projector with a filmstrip running through it. The images projected are what is seen on the screen. The filmstrip itself is comprised of all the images of the study, tiled to fit on the filmstrip. The user would scroll the film up or down to see images in either direction. Modalities like CT, MR, nuclear medicine, and lower resolution Xray images would be candidates for this category. We have designed a version of this for chest CT readings. Below, I list some of the design decisions and their motivation.

No separate Navigation view

Adding a navigation view would change or at least complicate our mental model of a filmstrip projector. Assuming that scroll operations were instantaneous, it was felt that radiologists know where they are in the study, and could easily move to a desired location, and that a navigation view would not serve an important enough purpose to warrant complicating the mental model.

Provide only W/L presets and scroll operations

A primary goal was to demonstrate that workstation readings could be as fast as lightbox ones. In order to compare similar things we intentionally limited the available operations to match only those provided with a lightbox: the ability to look at images at preselected W/L settings and to look over all the images. Until we have established that we can perform readings at a speeds similar to those on a lightbox, we are not including any other operations that might cause the reading times to increase; for instance, allowing the radiologist to play with an interactive W/L operator.

The two operations (W/L and scroll) must be instantaneous and easy

Having limited ourselves to only W/L and scroll operations we found that we needed to provide only five logical actions: choosing one of three W/L presets (lung, soft tissue, liver) and one of two scroll motions (forward or backward). After some debate and prototyping we eliminated using the mouse and choose to use the keyboard. We use three oversized function keys (F4, F5, F6) on the Sun 3 keyboard to select the three W/L settings. These keys were labeled. The spacebar, being the easiest key to hit was chosen for forward (down) movements and any other key on the keyboard mapped to a backward (up) movement. The keys are easily struck by a single hand which facilitates holding the dictaphone in the other hand. We have found that radiologists when using the mouse, often hold it in their dominant hand and then release the mouse to pick up the dictaphone with the same hand, which causes delays when switching back and forth between the mouse and the dictaphone. This is compounded when the interaction requires the use of both hands (e.g. keyboard and mouse in addition to a dictaphone).

Implementation

We have implemented this system on two different hardware configurations. The first is a Megascan single screen 2048x2560 display system. The second is a Sun workstation with two 1000x1000 monitors. The same software is used for both systems, with different low level image display routines depending on the capability of the hardware. It runs under the X Window System, and is written in the C programming language.

The low level interface is slightly different for the Megascan, as this system provides some extensions to X which are utilized to enable us to accomplish the realtime scrolling and W/L operations. On the Megascan we tile the images into the Megascan frame buffer and from there we can copy in realtime (1/9 of a second to update the 2048x2560 screen) a new screen of images to the video buffer. We are also able to perform any arbitrary W/L operation on the image data as it is moved from the 12 bit frame buffer to the 8 bit video buffer. Thus, we can perform any scroll and W/L operation in 1/9th of a second. We have found that with this throughput speed, the radiologist typing on the keyboard never gets ahead of the screen updates, so there is never any lag perceptible to the radiologist.

The implementation for the Sun workstation runs using only standard X. Thus it runs on any Unix workstation supporting X. Because most of the workstations in the class we are considering (those costing less than \$10,000) have 8 bit video buffers and no separate frame buffer, we had to choose a different approach for displaying the images. In order to get the speed necessary under X, the obvious choice was to preload images in memory for each of the three W/L presets. Thus three versions of the entire study windowed for lung, soft tissue and liver were computed and preloaded into pixmaps on the X server. This enables us to use the XCopyArea() function on the server to copy from a pixmap to the display screen resulting in updates rates of less than 1/10th of a second on the Sun workstations.

3.2 Screen space insufficient methods

In a sense, these are the situations that we cannot handle well at this time because of insufficient screen space. The user is unable to view all the information they desire at a single time. Most implementations that handle this situation attempt to provide some sort of navigation or more overall view to help you maintain a sense of what is in the patient study as well as what portion you are currently viewing.

For this situation I have chosen a mental model similar to the microscope. The images are arrayed on a two dimensional surface. The user is able to do two operations: roam around on the surface, and choose the level of magnification with which they view the surface. This enables them to zoom out and see the entire surface, or to zoom in and see the minute details of a specific region of the surface. Additionally, they can make small adjustments to their location by roaming, or make bigger adjustments by zooming out and then zooming in to the new location. This system is named PlainView.

In this case our design is based on reading mammograms. Our example protocol is to have 4 images (CC and MO of right and left breasts). Each image was digitized at

approximately 4000x5000 pixels, but then cropped to just show the breast resulting in 4 images approximately 2000x2500 pixels in size.

No separate Navigation View

By choosing the mental mode appropriately, navigation is accomplished by zooming. An overall picture is obtained by simply zooming out to see the entire surface, so no separate navigation view is required.

Limit to roam and zoom operations

In order to compare against the lightbox we have again limited the available operations to only those required to view the mammograms, zooming the display and roaming the display. No W/L capability is provided as the mammograms are acquired and read at a single setting.

Interactions simple and instantaneous

In this case there are three actions: roam (in any direction), and zoom in and zoom out. While one could limit the roaming to discrete choices of directions (e.g. up, down, right, left) our experience has been that a continuous choice is more natural and most preferred by the users. Thus, to support roaming, a device such as a mouse, trackball, or joystick is required. Our inclination is that the trackball might be the most effective device for this task, but given that a mouse is a standard accessory on inexpensive workstations and well supported under X, we choose to use the mouse for the roaming interaction. Additionally, since most mice on workstations have three buttons using one for roaming and the other two for zoom in and zoom out, allows us to execute our three operations all with a click of a mouse button. Roaming is done by depressing the left mouse button and dragging the mouse, resulting in the image panning in the direction the mouse moves. This is similar to grabbing the microscope slide and moving it under the magnifying lens. Clicking the middle mouse button zooms in and clicking the right mouse button zooms out. All the operations, panning, zooming in and zooming out are accomplished in realtime. It is especially important that the panning be accomplished in 1/10th of a second or faster to maintain smooth roaming. If the update rate is too slow, the lag results in jerkiness or tearing of the image which is disconcerting to the user as well as increasing their interaction time.

Implementation

PlainView has been implemented on several different configurations including a Stellar graphics supercomputer, a Megascan display system, and a Sun workstation. The same software is used for all systems, with different low level image display routines depending on the capability of the hardware. It runs under the X Window System, and is written in the C programming language.

The Stellar GS1000 computer supports copying of image data from main memory to the video buffer over a high speed (512 bit wide) bus in 1/60th of a second. This allows us to accomplish the roaming by storing the image in main memory and copying the new image location to the video buffer each time the user makes a roaming motion. The Stellar also supports several low level image processing operations in the graphics engine pipeline, allowing them to occur in realtime. We

were able to modify one of these routines to provide real time continuous interpolated zooming.

The Megascan display system supports rapid updates of the screen as described previously. The update rate of 1/9th a second is marginal though, with the users occasionally noticing the lag in roaming. The Megascan also supports realtime zoom in and zoom out by pixel replication. Since we store the original image at full resolution, we are mainly interested in allowing the user to zoom out (sample the image down to smaller sizes). Thus, while pixel replication is not a good choice for resampling images in general, it suffices for providing an overall view where accurate final detail is less critical.

On the Sun workstations we again stored all the possible display combinations in pixmaps on the server side of X so that we could quickly copy the image data into the video buffer. The trick here is to provide precomputed interpolated images because we cannot interpolate the images to a new size in real time. Based on previous experience, I choose to provide zoom increments in factors of two. Thus we precomputed the original image at full resolution at 4000x5000 by 8 bits, then proceeded to compute bilinear sampled down versions of the images at 2000x2500, 1000x1250, and finally stopping at 512x625 where we could view the entire image on the screen at once.

Storing the images requires approximately 27 Mbytes of main memory. Memory is relatively inexpensive compared to other parts of the workstation, such as the monitor, and the price of memory is rapidly decreasing, making tradeoffs that require lots of memory seems reasonable.

On the Sun we were able to achieve update rates of less than 1/10th of a second allowing us to smoothly roam as well as to zoom in and out in realtime. Note that the zoom in this case only varied between 4 discrete choices: full resolution, 1/2th resolution, 1/4th resolution, and 1/8th resolution.

4. Experience

4.1 FilmStrip

We have recently completed an experiment to evaluate the speed and accuracy of FilmStrip running on the MegaScan for chest CT readings. The Megascan was configured to show a 12 on 1 display format, yielding an image size on the Megascan very close to the normal size of chest CT film images.

The study was carried out in a similar fashion to our earlier experiment comparing FilmPlane to a film lightbox [9], with accuracy being measured by comparing the dictated interpretation report to the previous clinical report. The films were displayed on an alternator in the chest CT clinical reading area. As with the earlier FilmPlane study we found the accuracy of the workstation to be the same as the alternator viewed films. This time, however, we found that the reading times for FilmStrip on the Megascan were equivalent to those for the alternator [7,10].

We learned some additional information from observing the radiologists using FilmStrip.

Radiologist liked it. They all felt comfortable reading chest CTs with FilmStrip and indicated they would use such a device in the clinic.

Field of View. Most of the radiologists also indicated they liked having the single screen area (one screen) to look at; i.e. they preferred having the images moved

to their field of view (like an alternator) rather than having to move their head to see remote images on a lightbox or multiple monitors.

Scrolling. Several of the radiologists were initially confused by the scrolling. Hitting a key to scroll caused the images to scroll two rows on the screen. While this is optimal in the sense of maintaining context by keeping adjacent rows in front and back of the middle two rows of images, it is disconcerting because people tend to read to the bottom a page and then expect to start at the top of a page (book analogy, English languages) or to see a new line at the bottom of the screen (computer text scrolling analogy). In order to keep at least one row of context, the other options would be to scroll 1 or 3 rows instead. The radiologists, however, did not express a strong preference for any particular choice of 1, 2, or 3 rows to scroll when asked.

Window and Level. Because our images were taken indirectly from old clinical studies we did not have the actual W/L settings for each study. As a result, we arbitrarily choose "mean" W/L settings for lung, soft tissue and liver and applied these to all the cases. In some of the cases the radiologists felt that the W/L settings were not specific enough (especially the liver). For a clinical system it would be important to retrieve and apply the original W/L settings for each individual case.

Study Extent. One area where the navigation view was missed was in knowing the extent of the study. Our radiologist's initial dictation includes a description of the extent of the study. Because they could not see the entire study at once, they would scroll all the way through the study once just to see the extent, then back up and begin linearly scrolling through the study. To compensate for this we have enabled two additional function keys, HOME and END, that allow the user to jump directly to the beginning or the end of the study, respectively.

We are now testing a two screen version of FilmStrip on the Sun workstation to see if we get comparable results.

PlainView

At this time we are completing analysis of the mammography task and have not carried out a formal experiment using PlainView. We have initially prototyped PlainView on the Megascan and the Sun and have presented sets of four mammograms (CC and MO of the right and left breasts) to one of our mammographers. Her initial impression was that the PlainView mechanism is useable; however, from our observation of her, PlainView appears to be slower than film/lightbox and more cumbersome to use, especially on the Sun where we can only display 1000x1000 pixels at a time.

5. Discussion

The major point is that one can construct a medical image display application using standard off the shelf software and hardware that will provide both the accuracy and speed of a film/alternator. The software for both PlainView and Filmstrip is relatively simple, in our case requiring only a weeks time of someone familiar with X to code the applications. The hardware is standard off the shelf Sun sparcstations, supplemented with additional memory. The cost of the complete single screen Sun workstation with 32 Mbytes of memory was \$8,737 and the cost of the complete two screen Sun workstation was \$11,557.

6. Future work

We plan to extend the CT chest study to gather timings on 1 and 2 screen Sun versions of FilmStrip. We then plan to begin studying MRI and selected types of Xrays with lower resolution requirements for use with FilmStrip. For PlainView we will complete the mammography study and then begin work on other Xray images that require higher resolution than provided by current monitors.

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SESSION 17

Image Processing

Chair: Lee Monsein

A Simulation System for Planning Femur-Osteotomies Regarding the Actual Physiological Function of the Hip Joint

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Summary

Computerized 3-D imagery from computed tomography data represents in orthopaedics a powerful diagnostic aid. Many efforts have been made to implement methods for object visualization and manipulation in order to plan complex surgical operations. However most of the visualization methods are basically hardware dependent so that they can match real time demands, and most of the manipulation methods do not regard the actual physiology of the joints.

At our institute with financial support of AESCULAP AG (a major medical instrument factory) we have created a powerful 3-D surface oriented simulation tool, which enables the surgeon to automatically determine relevant anatomical parameters of the hip joint in order to plan a true to nature femur intertrochanteric osteotomy on triangulated models.

Introduction

The interaction of muscles, tendons and ligaments enables the normal motion of the extremities of healthy humans. Muscle forces are optimally utilized by means of the simple mechanical principle of lever action [2,4]. Both trochanter (lesser and greater) are fundamental points of attachment for the iliofemoral and pubofemoral ligaments which after an osteotomy will undoubtedly be shifted thus altering the geometrical relationships of the hip joint. It is though necessary besides taking in account the complex geometry of the hip to determine to a vast extent the side effects on the ligaments and muscles while manipulating the joint. In order to accomplish this the interaction of the following parameters must be examined [6]:

- Corpus-collum-diaphysis angle,
- antetorsion angle,
- flektion and extension,
- lateralisation and medialisation,
- shifting in the sagittal plane,
- position of the trochanter,
- virtual collum length.

Femur head coverage, which seems to be essential for a healthy force flow through an optimal distribution of stress in the acetabulum [1], can actually be defined as a function of the condyle rotation about its center .

Resent applications based either on surface or volume oriented graphics suffer from the inability to consistently determine these parameters. Moreover manipulation tools like independent motion or resection features should be defined on terms of the above mentioned criteria [3,5].

This paper presents simple methods to determine the corpus femoris axis, collum femoris axis and knee axis as well as the condyle center which will be used to simulate a true to nature intertrochanteric osteotomy.

Determination of the shaft axis

Bone structures from volume data - leaning on the computer tomography approach of image sequences - is converted into a set of triangulated bodies with traditional computer techniques. First the model of the femur is separated in two parts by interactively choosing the sectioning plane in the intertrochanteric zone. This plane will be used as reference to compute the resection planes after having altered the position of the femoral head.

The starting point of the shaft axis is the centre of inertia of the slice with the greatest area in the knee region. The end point of the axis is the one with the minimal total distance to the intersection points of the lines joining the start point with the centres of inertia of the following slices in a plane parallel to these. In other words, there are $P_i(x_i, y_i)$ where $i = 1, 2, \dots, N$ and the Point $P_0(x_0, y_0)$ following equation satisfies:

$$Z(x_0, y_0) = \sum [(x_k - x_0) + (y_k - y_0)]^{1/2} \Rightarrow \text{Min!}$$

Where the sum is to be done over $k=1$ to N .

Determination of the condyle centre

The centres of inertia of the remaining slices, which describe the femur head (the femur has been previously separated in distal and proximal parts) are computed and a first approximation of the centre of rotation is given by the centre of inertia of the slice with the minimal ratio of its axis diameters of inertia. In other words the slice, which most resembles a circle, will be chosen. About this point a search sphere is defined in which a second sphere, that optimally approximates the condyle, will be computed. This later one has minimal total distance of the femur head points lying in the target sphere to its surface.

It is obvious that the method to compute the target sphere will not work well on heavily distorted femoral heads. Therefore an alternative interactive method was implemented to place and dimension the target sphere through dials in a four view dynamic window.

Determination of the collum femoris axis

So far the shaft axis and the condyle centre have been computed. To automatically find the collum femoris axis, a perpendicular from the condyle centre to the shaft axis will be fallen. Considering the radius of the condyle approximating sphere and the length of the distance between its centre and the femur shaft, two normal planes to the perpendicular will be chosen to determine the collum femoris axis in the following manner: The planes will be tilted about its point of intersection with the perpendicular in order to obtain a minimal intersection with the femur. The axis can now be built by joining the centres of inertia of the given intersections.

Here again it is possible to interactively position the planes with dials in a four view dynamic window.

Planing the therapy

To plan an osteotomy the model of the femur is separated in two parts, as it has been done so far. The sectioning plane has to be interactively determined by the surgeon and will be used as reference to determine the wedge of the intertrochanteric zone, which will have to be removed in order to achieve the desired correction of the hip joint. To accomplish this the surgeon can rotate through dials the proximal part of the femur in the acetabulum about the collum femoris axis and two more axes, which lay in a plane normal to the later one and build together an orthogonal system having its origin at the center of the femoral head. At the same time the angles collum-corpus-diaphysis and ante-torsion are computed and

displayed in real time. Finally the distal part of the femur can be shifted in the previously determined plane as well as normal to it.

After having changed the geometry of the femur in the above specified fashion, the intersection of the distal and proximal parts of the femur represents the part of the bone which will have to be resected.

Results

The automatic methods to determine the relevant anatomical parameters of the hip joint were tested on various femora with satisfactory results. An alternative method to determine the collum femoris axis is to try to approximate the neck of the femur with a cylinder.

The crucial advantage of this method to simulate the operation is that the hip joint is manipulated in terms of its actual anatomical parameters and that the necessary operative procedure is a mere by-product of the simulation, quite on the contrary of conventional surgery simulation packages where sectioning tools without points of reference lead to a tedious and sometimes long trial and error iteration.

Another highlight of the simulation package which will just be mentioned here is that with the results of the simulated osteotomy the surgeon can also choose the means and plan the way in which the operation should take place through simulated instrumentarium.

Conclusions

Simple reliable methods have been presented to determine relevant anatomical parameters of the hip joint in order to perform a true to nature intertrochanteric osteotomy.

The corpus femoris, collum femoris and knee axis, which are essential to determine the possible therapy, can be automatically or interactively found. With the help of the collum femoris axis and the center of rotation of the caput femoris, which is also automatically or interactively found, physiological motion of the actual hip joint can be simulated in real time colour shaded 3-D space.

The tool package is written in 'C' and its graphic standards are PEX, PHIGS and MOTIF based on the X-Windows-System so that a maximum on portability is achieved.

Future work includes femur head coverage, penetration, static studies as well as optimization algorithms.

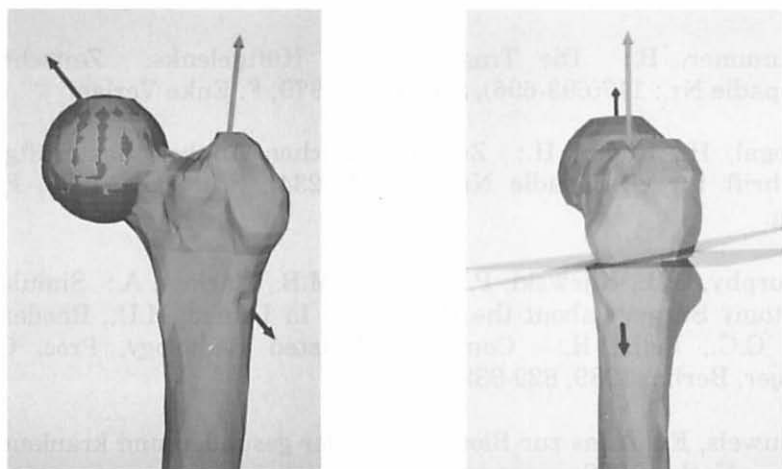


Figure 1 and 2: Founded anatomical parameters of the femur, and extension of the femur by rotation of the proximal part about the collum femoris axis (respectively).

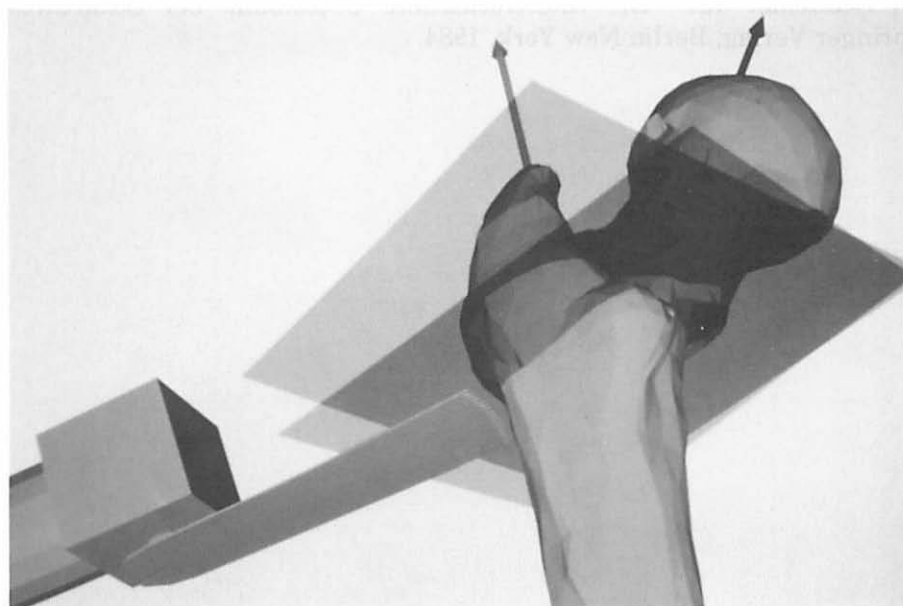


Figure 3: Femur geometry has been altered; the part which has to be resected is delimited by the planes. Operation strategy can be planned in advance through simulated instrumentarium.

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A System for 3-D Reconstruction of the Left Ventricle and Quantitative Analysis of Regional Wall Motion

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I. INTRODUCTION

Quantitative measurement of regional myocardial properties such as wall motion and wall thickening coupled with measurements of global properties such as ejection fraction and ventricular mass provide information of extreme importance in the evaluation of the failing heart. Ideally the techniques used to assess these regional and global properties should be non-invasive, should avoid the use of ionizing radiation, and should allow assessment of the required cardiac parameters with the smallest possible number of independent procedures. Magnetic resonance imaging (MRI) meets the criteria for patient safety and most of the information required to quantify the myocardial parameters mentioned above can be obtained from gated MRI images of the heart (4). MRI has been used to independently assess regional ventricular wall thickening (1), ejection fraction (2,7), and ventricular mass (4).

Quantification of regional wall motion, however, has proved to be more difficult and less accurate than calculation of the other ventricular mechanical parameters. A major difficulty in quantifying wall motion is the fact that it is extremely difficult to non-invasively track the motion of specific points on the endocardium due to factors such as endocardial infolding (3), translational movement of the heart within the chest and rotational movement of the heart around its longitudinal axis (5) which occur during contraction. Because of these complicating factors, quantification of regional wall motion is more a process of modeling than of determining the motion of specific points on the myocardium. The best known methods of modeling the motion of the endocardium involve the use of ventriculograms. Ventriculogram analysis techniques include the construction of hemiaxes (10), construction of radii or sub-areas on the ventriculograms (8) or construction of chords between superimposed end-diastolic and end-systolic ventriculograms (8,9). Ventriculogram techniques suffer from

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two major defects: they are projective and thus reduce three dimensional structures into two dimensions, risking the loss of important data; and they are invasive, involving radiopaque dye injection.

Methods used to calculate wall thickness involve taking tedious and repetitive measurements from individual MRI images. A much greater degree of automation in the production of quantitative data of this type is required before the use of MRI to produce these data will be practical on a large scale. Methods used to calculate volumes, ejection fractions, and myocardial mass also usually require the use of simplifying assumptions concerning the geometry of the ventricle. The intrinsic three-dimensionality of MRI allows the possibility of using MRI images to reconstruct the shape of the ventricle in three dimensions. Three dimensional reconstructions could then be used to directly and automatically quantify regional wall motion and regional wall thickening, as well as to calculate total myocardial mass, volume and ejection fraction thus allowing determination of several important cardiac parameters non-invasively from the data obtained in a single scanning session.

The software package which we have developed allows a highly automatic reconstruction of the shape of the left ventricle in three dimensions from MRI images and uses the reconstructed models to automatically calculate regional wall motion, ventricular volume and ejection fraction. The package will be extended to include calculations of myocardial wall thickness and myocardial mass.

II. DATA ACQUISITION

Scans of the hearts of normal volunteer subjects were produced in the axial plane on a General Electric Signa 1.5 Tesla MRI scanner using Advantage 4.7 software. Images were produced with T1 weighting, using respiratory compensation and using SAT bands in all 6 planes. TR was 967.7 ms and TE was 11.0 ms. The sharpest and most accurately gated images of the ventricle were produced using pulse gating and monitoring scan timing by observing the artifact produced by the magnetic fields in the EKG signal. This method consistently produced better results than those produced using EKG gating alone because it was very difficult to adjust the EKG triggering level on the equipment available. The use of EKG guided pulse gating produces excellent images at end-diastole but it is difficult to isolate end-systole with this method.

Several series of images were taken at both end-diastole and end-systole and a single composite image series was constructed at each cardiac phase by interleaving the separate images according to their superior-inferior level. The use of such a composite image series allowed us to obtain more data for use in three dimensional reconstruction thus increasing the accuracy of the reconstructed model. Typically, the interslice distance in an end-diastolic composite image series was 5mm. Because end-systole has a shorter duration than end-diastole, fewer images can be produced in a single end-systolic series and the typical interslice distance of an end-systolic composite image series was 10mm. Images and related alphanumeric data were archived on magnetic tape and transferred to Sun Microsystems SPARCstation2 workstations. The three dimensional reconstruction and measuring software was

created on the SPARCstation2 workstations in the C programming language using the Open Look graphical user interface and the XGL graphics rendering package.

III. DETERMINATION OF ENDOCARDIAL AND EPICARDIAL BOUNDARIES

In order to produce three dimensional solid models of the left ventricle it is first necessary to produce unambiguous contours of the endo- and epicardial surfaces in each MRI image at end-diastole and at end-systole. It is very difficult to strictly segment the pixels of cardiac MRI images by tissue type and interpretation of cardiac MRI images is complicated by image artifacts which result from uncontrollable factors such as turbulent blood flow, ventricular motion, imprecise scanner triggering, and patient movement. The inability to strictly segment by tissue type makes location of endo- and epicardial surfaces more difficult.

The problem of boundary detection was approached using a combination of edge detection techniques commonly used in image processing and machine vision applications and interactive user input. First, each MRI image is passed through a series of filters designed to locate edges within an image. The exact combination of filters to be used can be altered by the user since images from different patients or images reconstructed by different scanner software often vary widely in overall brightness and contrast. Boundary pixels selected by the edge detection algorithms are indicated by setting pixels to a non-gray color. Pixels located on unambiguous boundaries are selected extremely accurately by these techniques, but the inherent noisiness of cardiac MRI images also results in the selection of many non-boundary pixels. Image noise can also occasionally cause true boundary locations to not be identified. For these reasons interactive user input is required to complete the process of boundary identification by using a mouse to select additional boundary pixels not previously selected and to erase or unselect pixels previously selected erroneously. Interactive user input is also needed to define the atrio-ventricular boundary, especially during end-diastole when the mitral valve is open. When the

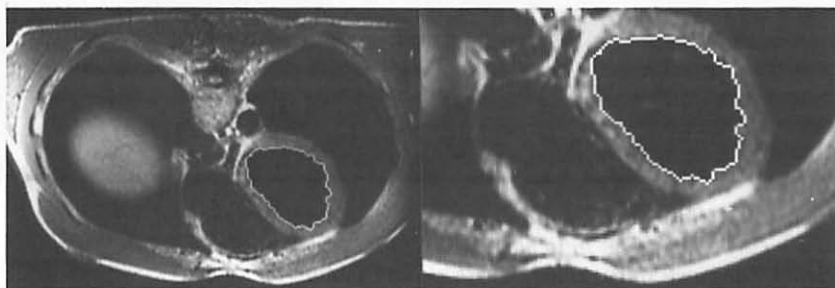


Figure 1. Boundary detection in MRI images. Image on left is a complete 256 X 256 pixel image. Image on right is magnified to emphasize the left ventricle. The boundary contour determined for this section is shown in white.

user is confident that the desired boundary is closed and is correct he or she is required to select a single location on the inside of the enclosing boundary and the program then automatically deselects all image pixels which are not located on the closed boundary contour. An example of a cardiac MRI image and an endocardial

ventricular boundary contour determined by these techniques is illustrated in Figure 1. It is worth noting that most of the pixels on the boundary contour shown in white in Figure 1 were automatically selected by the program, typically fewer than ten percent of pixel selections or deselections are made interactively by the user. Using the boundary contour detection program, boundary contours are determined for each image in an end-diastolic or end-systolic composite series of images and the collection of all non-collinear points on all the boundary contours are used to construct the three dimensional solid model of the ventricle.

IV. THREE DIMENSIONAL SOLID MODELING OF THE VENTRICLE

Reconstruction of a three dimensional solid from a set of boundary contours is accomplished by interconnecting points on the boundary contours into a closed surface which describes a simple non-convex polyhedron. The surface of a simple polyhedron is composed of polygons which form a continuous surface with no holes. Each edge in a simple polyhedron is shared by only two polygons and each vertex is a part of three or more edges. Each vertex in the ventricular solid models represents a single measured point from one of the boundary contours. The solid model is constructed by connecting the boundary points from each contour to the next contour in succession. The interconnection algorithm assures that the orientation of the contours is preserved and that any one point is connected to the closest point on the next contour. The resulting solid represents the shape of the volume enclosed by the entire set of contour points. The interconnection process is illustrated in Figure 2 which shows from left to right, a complete set of boundary contours, the lines interconnecting boundary points, and the same solid model rendered with smooth shading. These simple polyhedral solid models are

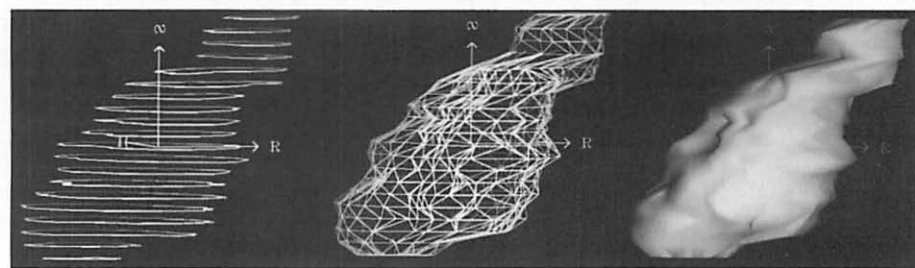


Figure 2. Solid model creation process. Left - A set of ventricular boundary contours. Center - The solid model created by interconnecting contour points. Right - The same solid rendered with smooth shading.

represented using a modification of the data structure proposed by Mantyla (6). The use of this data structure facilitates the process of cutting a solid model along a plane, a process which is used to determine the long axis and to measure wall position.

V. MEASUREMENT OF WALL MOTION AND VOLUMES

It is essential that some frame of reference be established within the ventricular system which is used as a basis for measurement of wall position in both end-diastolic and end-systolic ventricular models. Ideally this frame of reference will also minimize individual variations in ventricular anatomy and orientation to allow comparisons of wall motion measurements between patients. The long axis of the end-diastolic ventricular model provides the needed frame of reference. The long axis is defined as the line extending from the center of the valve plane through the ventricular apex. The apex is defined as the furthest point from the center of the valve plane. There is no unambiguous method of identifying the valve plane automatically so this step requires interactive input from the software user. The user is given the ability to interactively rotate the three dimensional solid model around all three major axis to allow examination of the model from any point of view. To establish the long axis the user is expected to position the ventricular model so that the area containing the valve plane is uppermost on the computer screen and then use a mouse driven slider to position a cutting plane across the model through or just below the valve plane level. The solid model of the ventricle is then cut at the position of the plane. The portion of the solid model above the cutting plane is removed since it represents valvular structures rather than myocardium, and a new trimmed solid is formed from the portion of the original model which was located below the cutting plane. The flattened area which is produced by trimming the solid is defined as the valve plane and the center of this area is taken as the basal point for the long axis. The trimmed solid is then searched for the vertex located furthest from the basal point and the location of this vertex is used as the apical end of the long axis. The left part of Figure 3 shows a solid model of the endocardial surface at end-diastole along with the long axis determined by the method described above. The

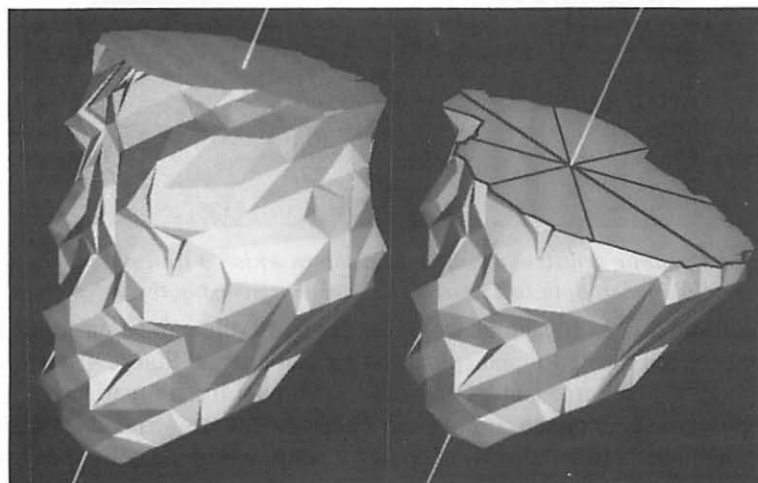


Figure 3. Myocardial wall position measurement. Left: Left ventricular solid model trimmed at valve plane. Long axis shown in white. Right: Same model cut perpendicular to long axis. Black lines indicate distances from long axis to myocardial wall.

cutting plane used to determine the valve plane position in the end-diastolic endocardial model is then also applied to the end-diastolic epicardial model and both the endo- and epicardial end-systolic models.

The long axis determined in the end-diastolic endocardial model is then used to measure wall position in all four models for a given patient. Since it is extremely difficult to track the motion of specific points from the end-diastolic ventricle to the end-systolic ventricle, it was decided that wall position measurements would be taken at equal intervals along the long axis in all four models for all patients. At each location along the long axis, wall position measurements are taken at equal radial angles in a plane perpendicular to the direction of the long axis. This process is illustrated in the right-hand image of Figure 3 for a single long axis point on an end-diastolic endocardial model. In this case measurements were taken at equal angles of 45 degrees as illustrated by the lines radiating from the long axis. It should be stressed that more than eight measurements are taken at each segmental level; eight measurements are shown in Figure 3 only to simplify the illustration. On each measurement line radiating from the long axis, wall motion is determined by the difference between wall position in the end-diastolic and end-systolic endocardial

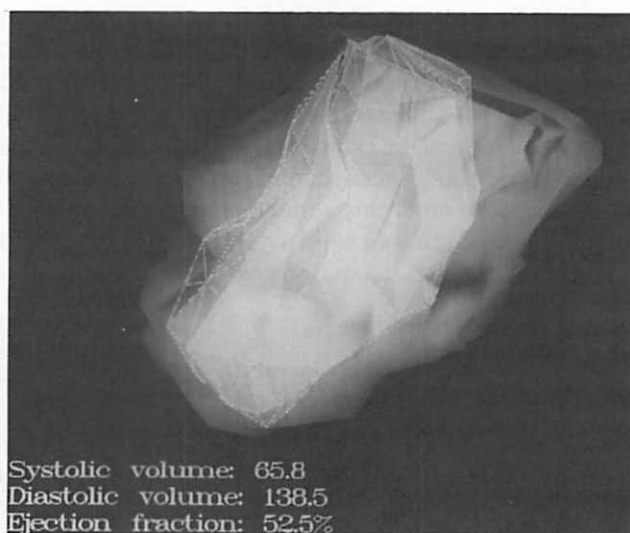


Figure 4. End-systolic ventricular solid model shown within a transparent end-diastolic ventricular solid model. Both solid models have been trimmed at the valve plane.

models. Wall thickness at each phase of the cardiac cycle can be calculated by the difference between the endo- and epicardial measurements. Figure 4 shows an end-systolic model inside a transparent end-diastolic model for comparison.

All polygons contained in a ventricular model are triangles. Using this knowledge volume is calculated by choosing a point within the solid then using this point to form a tetrahedron with each surface triangle and summing the volumes of the tetrahedra.

VI. CONCLUSIONS

This study has demonstrated the practicality of reconstructing 3-D solid models of the left ventricle from MRI scans and has shown that these solid models can be used to automatically quantify several ventricular performance measures including measurement of wall motion, ventricular volumes and ejection fraction. At present, wall motion and ejection fraction calculations are not highly reliable since the inability to adjust EKG triggering level on the available hardware results in inaccurate end-systolic images. The accuracy of end-systolic images should improve when precise EKG gating is available. At the time of this writing the software is being extended to include measurements of myocardial thickness and myocardial mass. For this method to be useful as a clinical tool a database of normal average wall motions and thicknesses must be established to allow comparisons with data from individual patients. It is the intention of the authors to construct such a database and to make additions to the software to allow it to produce bulls-eye diagrams or other easily readable presentations to illustrate how far a patient's regional wall motion and wall thickness deviates from normal average values.

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Using Surface Curvatures for Registration of 3D Image

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I Introduction

Modern medical imaging techniques, such as Nuclear Magnetic Resonance or X-ray computed tomography provide three dimensional (3D) images of internal structures of the body. The first stage of an automatic treatment of these images consists in the segmentation of the different anatomical structures. The more classical approach is edge detection which provides points corresponding to the boundaries of the surface forming the 3D structures. We focus here on the next stage which consists to characterize the local geometry of these surfaces. We consider next the issue of matching 3D objects extracted from medical images. We assume that high curvature points of the object surfaces often correspond to meaningful anatomical features, and that they tend to be stable to some deformations occurring when the objects are extracted at different times, or in different positions, or from different patients. In particular, we focus on the lines of extremal curvatures (crest lines).

We have explored different techniques to compute the curvature informations and we present them in section II. The next section presents the notion of curvature extrema and also different possible implementations. The last section is concerned with the registration stage. Each point will be illustrated by recent concrete examples, and we shall present the registration of two different 3D images of a given skull with subvoxel accuracy (accuracy about 1 mm). The dry skull was scanned twice on a GE-CGR CE12000 CT system. The scanning parameters are those typically used for routine examinations : Pixel size is 0.3925 mm, Slice spacing is 3 mm, Slice thickness is 5 mm. Both sets include about 50 slices. Remaining problems and future research will be discussed in the conclusion.

II Curvature Computations

We present here two approaches to compute the **principal curvatures** on a surface point. The principal curvatures correspond to the higher and the lower signed curvature. The principal directions associate to the two principal curvatures are orthogonal.

The first approach [MAS91] consists in approximating locally the surface points by a surface model. This classical technique is characterized by :

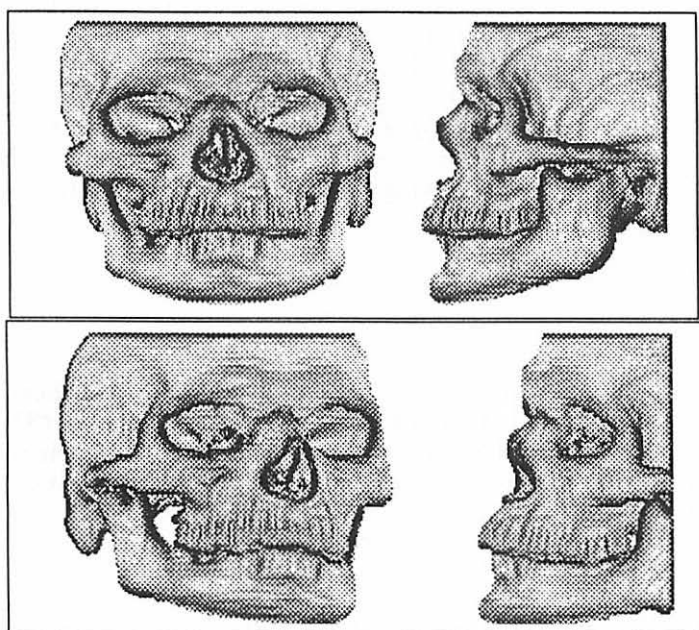


Figure 1: Perspective views of the maximum curvatures for the two positions, no rendering is done : the magnitude of the maximum curvature is displayed (up left : face view for position A, up right : profile view for position A, bottom left : face view for position B, bottom right : profile view for position B). The parameters of the filters are : $\alpha = 1.0$ for the first derivatives, $\alpha = 0.7$ for the second derivatives

- choice of the surface model.
- informations taken into account : points, normal vectors, uncertainty.
- technique of fitting : least squares, kalman filtering.

This method gives regular results for several reasons :

- the result on two neighbouring points depends on very similar points sets.
- the fact that normal vectors are taken into account improves smoothness because they are issued from a filtering technique [Der87].
- the Kalman filtering technique allows to use explicitly the uncertainties of the input data [MAS91].

The main drawback of this approach is that we need to calculate a neighbourhood graph on each surface point and it requires prohibitive computation time when implemented on a serial machine.

The second algorithm extracts directly the curvature information from the first and second order partial derivatives of the image [MBF92] by assuming that the surface has locally a constant intensity (i.e., the 3D image gradient at an edge point corresponds to the normal to the surface). This assumption leads to the following formula of the curvature on a surface point m along a direction $\vec{t}$:

$$k_{\vec{t}} = -\frac{\vec{t}^T H \vec{t}}{\|\vec{g}\|} \quad (1)$$

where $\vec{g}$ is the surface normal vector on m and H is the hessian of the data image (we notice that we use the 3D Deriche filters [Der87, MDM91] to compute the partial derivatives of image data). The principal curvatures computation is also reduced to the following constrained optimization problem:

$$\begin{aligned} & \text{Optimize } k_{\vec{t}} \\ \text{s.t. } & \begin{cases} \langle \vec{t}, \vec{t} \rangle = 1 \\ \langle \vec{t}, \vec{g} \rangle = 0 \end{cases} \end{aligned}$$

III Lines of curvature extrema

We call *maximum curvature* (resp. *minimum curvature*) the principal curvature which has the maximum (resp. minimum) absolute value. The associated directions are called maximum (resp. minimum) curvature direction. We will call a *ridge point* (resp. *valley point*) any point whose maximum curvature in the associated curvature direction is locally maximal (resp. minimal). Sets of connected ridge or valley points form *crest lines*. Because of the anatomical significance of crest lines, and because of their stability (in terms of the different mathematical and algorithmic methods to obtain them, and of their existence on every human body at similar locations) they can be used to reference positions and features on the skull for different individuals [Cut89]. On the other hand, the lines carry rich topological information of the complex surfaces on which they lie and thus provide a good overall description of the surfaces.

We have investigated two methods to obtain these points as for the principal curvatures computation:

- The first method uses the maximum curvatures field and maximum curvature directions field obtained by the local approximation technique and considers a discrete version of the definition given above (see for results Fig. 3). We consider on the tangent plane a cone directed by the maximum curvature direction and we examine if, locally, the maximum curvature is optimal.

- The second method consists to apply the analytic definition given above, i.e. to compute the directional derivative of the maximum curvature along the correspondent principal curvature direction. The curvature extrema correspond to the points for which this directional derivative vanishes (see for results Fig. 2).

The two versions give similar results. We notice nevertheless that the second method allows the use of the technique of zero-crossings which provides directly lines [TG92]. For more details concerning the curvature computations, one can refer to [MDM91, MAS91, MBF92]. Because of their stability, these characteristic points allow a registration operation.

IV Toward an automatic registration [GA92]

The crest lines are stable characteristics with respect to rigid transformation (i.e. translation or rotation).

We present an original solution to the space curve matching problem, whose specificity is to preserve a suitable computational complexity with numerous curve models, featuring noise and partial occlusion.

Our approach follows works by [KHW89] based on a two step method :

- A first goal is to compute differential and geometric features of the data. B-splines provide the analytic description of the curves with a specified order of differentiability. Thus we can compute curvature, torsion and Frénet frame features along the crest lines. We introduce an explicit minimization of curvature together with knowledge of the surface in 3-D on which the curves lie to determine a least squares approximation.
- A second step is to register B-spline curves. We use a geometric hashing technique which consists in storing differential and geometric information of model curves in a hash table. The hash table allows one to generate hypotheses of Frénet frame correspondences. It operates in sub-linear time with respect to the number of model curves. The correspondances are gathered as parameter values in a transformation space. Clusters in this space are processed with a Kalman filter and provide matchings of sub-curves. Many curves may be processed simultaneously with this technique.

For more details, consult [GA92]. Characteristic curves from medical data are matched with our technique (see Fig. 3) .

V Conclusion

We have presented an original solution to the problem of registering two 3D images. Crest lines are first extracted from the images with various techniques. Then crest lines from the two views are associated with a geometric hashing based method. This whole process may be completely automatic, and deserves a wide use in a medical environment to process a large database of images. The reader may consult [TG92] for the last developments of the method.

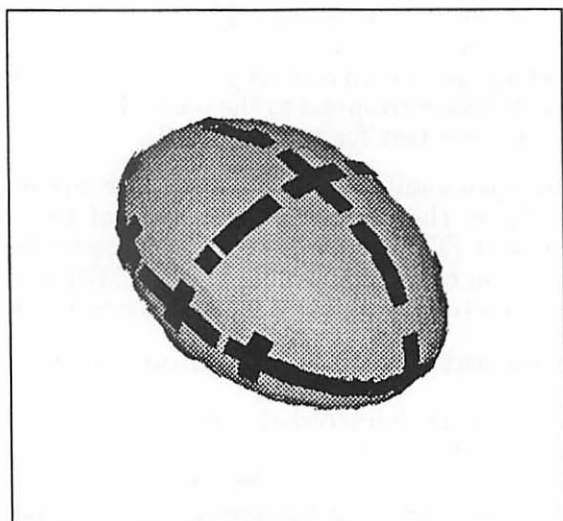


Figure 2: Curvature extrema on a synthetic 3D ellipsoid

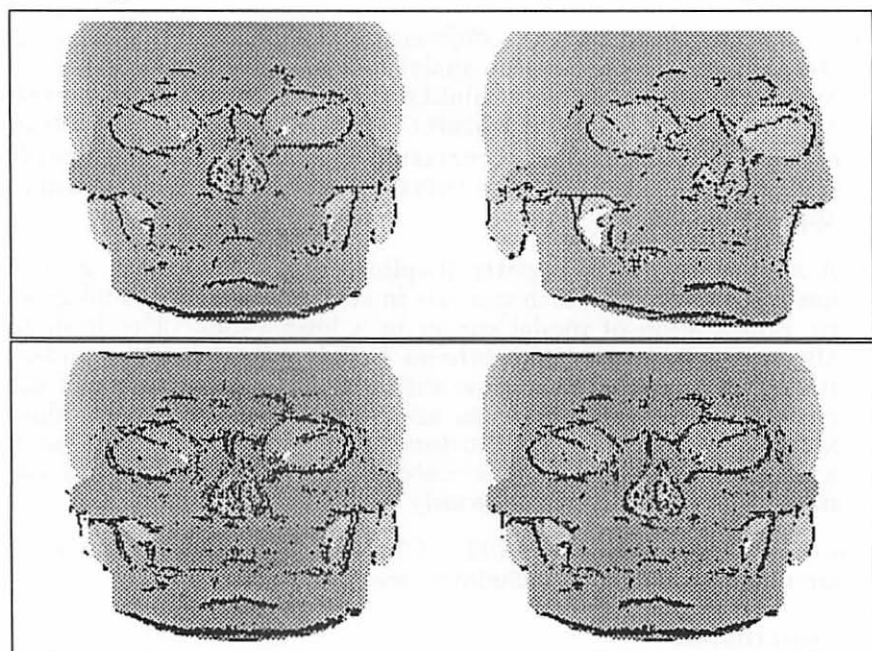


Figure 3: Up, curvature extrema of the skull in the two positions obtained with the local approximation technique. Down left, registration of the two images obtained after transforming the points of the second view according to the transformation discovered by matching the chin curves. The best correspondances are along the chin points. Figure in the bottom right shows the improved correspondance of ridge points due to the global transformation determined from chin and orbit points matches

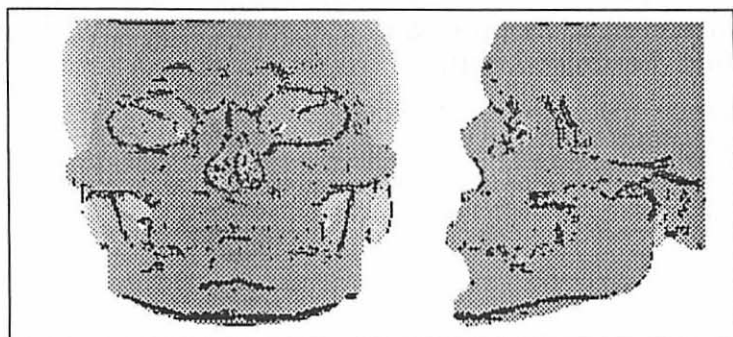


Figure 4: Profile views of the improved correspondance of ridge points due to the global transformation determined from chin and orbit points matches

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Development of a Macintosh-II Based Spectrum Analyzer for Quantitation of Doppler Signal Enhancement With an Ultrasound Contrast Agent

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I. INTRODUCTION

Since its introduction, Doppler ultrasound (US) has been widely accepted in clinical medicine and has become a common means of evaluating the vascular system. Although conventional Doppler equipment used in clinical practice typically includes a number of functions for display and quantitation of various aspects of the Doppler signal, the user is limited by the design of the particular scanner being used. For example, the Doppler power spectrum is not provided by clinical US units.

This project involved the development of a Macintosh based virtual spectrum analyzer for off-line quantitation of Doppler power. The virtual spectrum analyzer was tested with computer simulated audio signals and an electronically generated pure audio frequency tone. After validation, the instrument was used to quantitate enhancement of Doppler signal in the rabbit carotid artery after intravenous injection of an ultrasound contrast agent.

II. MATERIALS AND METHODS

HARDWARE/SOFTWARE

A Macintosh IIfx personal computer (Apple Computers, Cupertino,

California) was equipped with an NB-A2100 analog-to-digital converter board (National Instruments, Austin, Texas) and an NB-DMA2800 block-mode direct memory access and GPIB interface board. The converter board provides high fidelity analog-to-digital conversion with sample rates up to 48 kHz. Two sampling channels are provided which allow simultaneous acquisition at 16 bit resolution and a signal range of ± 2.828 V. The dynamic range is 93dB. The block-mode direct memory access and GPIB interface board is a 32-bit DMA controller board used for high-performance direct memory access to other boards in series. This NuBus-to-GPIB interface further allows data transfer between the Macintosh II and IEEE-488-compatible instruments at transfer rates of 1 Mbyte per second for read operations and 700 Kbytes per second for write operations. For this project, the DMA controller was only needed to provide rapid, high fidelity transfer of digitized signal data from the NB-A2100 board to memory.

LabView 2 system software (National Instruments, Austin, Texas) is a menu driven object-oriented programming environment that produces computer simulated or "virtual" instruments (VIs). Each VI consists of a graphically generated front panel and underlying block diagram. The graphical user interface of the VI or front panel simulates the front of a laboratory instrument where input icons (knobs, switches, dials) and outputs (graphs and gauges) are selected from a pull-down menu and customized for each VI. The logic driving the VI is defined on the block diagram where controls, indicators, arithmetic and logical operators, and subordinate VIs are interconnected or "wired" with a graphical editing tool. The completed block diagram resembles a conventional electronic circuit diagram.

Virtual instruments were developed to acquire and analyze audio signals. The signal acquisition VI allows user input of sampling frequency, channel specification, and number of samples. A real time graphical

representation of the digitized signal is displayed. The user initiates storage of an acquired digital signal to disc with a virtual toggle switch.

The signal analysis VI allows the user to specify the number of data points or alternatively the heart rate and number of cardiac cycles for an audio data set. A Hanning filter is applied to the signal and it is passed to a library VI that calculates the power spectrum. A user defined frequency window from the power spectrum is displayed and the mean Doppler power in the specified window is calculated.

VALIDATION EXPERIMENTS

Validation of the software design was achieved by analysis of computer synthesized signals. A VI was written to generate a signal that consisted of the summation of 3 sine waves where the phase, frequency, and amplitude of the sine waves could be varied. These computer simulated audio signals were processed with the spectral analysis VI to confirm accurate separation of frequencies and determination of frequency component powers. The acquisition VI was tested with digitization of a pure audiofrequency tone from a Simpson model 422 audio signal generator.

RABBIT CAROTID ARTERY EXPERIMENTS

The power spectrum analyzer was used to determine the dose-response curve of emulsified perfluorooctylbromide (Perflubron, Alliance Pharmaceutical Corp., San Diego, CA), a Doppler contrast agent. Six adult white rabbits were each studied on 2 different occasions for a total of 12 experiments. Approval by the institutional animal care and use committee was obtained and all guidelines were followed.

Heart rate was constantly monitored. All experiments were performed with an Acuson 128 ultrasound scanner (Acuson, Mountain View, CA). A 7 MHz US transducer was secured over the carotid artery with an armature in a position that maintained a strong, consistent arterial waveform. The audio signal gain was set manually so that the signal was weak yet clearly audible. The position of the transducer and audio gain of the scanner were not changed once the experiment began. The audio output port of the US unit was connected with stereo cables to a Sony EVS-900 high 8mm tape recorder (Sony Corporation of America, Park Ridge, NJ) which served as an intermediate storage medium for convenience.

Each experiment consisted of a series of 3 samples at each of 6 dose levels of a 45% weight/volume emulsion of Perflubron (0, 0.5, 1.0, 1.5, 2.0, and 2.5 ml/kg body weight). Contrast injection was through an ear vein. Because the intravascular half-life of Perflubron is long (14-43 hours)(1), repeated doses of 0.5 ml/kg were assumed to be cumulative. The first of the 3 sequential audio signal samples for each dose level was obtained no less than 3 minutes after contrast injection to ensure adequate mixing in the intravascular space. Three additional rabbits were examined in the same manner following incremental injections of normal saline.

Recorded samples were digitized from the Sony recorder with the Acuson VI at a sampling rate of 28 kHz. Digitized signals were processed with the spectrum analysis VI. For each sample, the mean Doppler power of the audio signal for 2 consecutive cardiac cycles in the 400 - 3000 Hz frequency window was determined. The frequency window effectively served as brickwall high and low pass filters to remove low frequency, high amplitude clutter and noise above the expected maximal Doppler frequency shift.

STATISTICAL ANALYSIS

For each of the 12 experiments, the mean powers of the 3 samples taken at each dosage level were averaged. These averaged powers were each normalized by dividing by the baseline averaged mean power (mean power at the 0.0 ml/kg dose level) to give a power ratio for each dose level. Linear regression and analysis of variance were then performed.

RESULTS

Processing of the computer simulated audio signals correctly separated component frequencies and correctly predicted their powers as determined from visual inspection of power spectrum plots. Acquisition and processing of the audio tones generated by the audio signal generator correctly predicted the frequencies for all samples below the Nyquist frequency (14 KHz).

Administration of Perflubron results in a linear dose-response curve over the dosage range tested. Linear regression of power ratio on Perflubron dose showed excellent linear correlation with a slope of 2.78 and an intercept of -0.129. The coefficient of determination equaled 0.986 ($p = .0124$). The overall ANOVA results were $F = 23.65$ and $p = .001$. No statistically significant difference in the power ratio resulted from the incremental injections of normal saline.

DISCUSSION

Perflubron is a brominated fluorochemical that has been used as a contrast agent for radiography, CT, MRI, and US (2). Because it is not water soluble, an emulsified preparation is used intravascularly.

Although emulsified Perflubron has been shown to enhance Doppler signal in observational studies (3), the degree of enhancement has never been quantitated.

Other investigators have quantitated Doppler contrast effects of sonicated microbubbles and air-filled human serum albumin microspheres by measuring power of the Doppler signal (4,5,6). Specialized spectral analysis equipment or customized US units were used by both of these groups. In contrast, this project illustrates how a personal computer with relatively minor and inexpensive modifications can serve as an adjunct to conventional imaging equipment in quantitative investigations. This type of equipment opens up this line of technical investigation to a larger body of researchers.

The use of the Sony recorder greatly simplified the project by allowing physical separation of the computer from the US unit. Although the potential for distortion of the audio signal exists, the tight specifications of this and other high-fidelity recorders make significant distortion highly unlikely. Direct access to the quadrature output of the US unit would be a more optimal method for quantitating Doppler signals because the quadrature output is not subjected to signal processing by the internal (and proprietary) US system software.

This project serves as an example of only one of the myriad of potential applications of virtual instruments in radiology research. Ease of programming and flexibility are two of the greatest strengths of the LabView 2 system. The user-friendly front panels and programming interface provide a comfortable environment for a range of investigators from the research scientist to the computer neophyte. Virtual instruments may be easily modified to meet changing investigational needs. Because all VIs may themselves become subVIs, complex instruments may be built from simpler free-standing components. This feature allows for efficient project development and sharing of software between institutions.

Software systems similar to LabView 2 are becoming available for other computer platforms and it is likely that use of virtual instruments will become commonplace in radiology labs.

This project supported in part by Alliance Pharmaceutical Corp.

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Enhancement of Digital Angiographic Images Using Motion-Compensated Prediction

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I. Introduction

Digital Subtraction Angiography (DSA) is a clinical imaging technique that deals with the digital processing of Roentgen video image sequences. The digital image sequence is obtained during the injection of the contrast material in the patient's arteries. In DSA the aim is to extract information that is produced by the additional X-ray attenuation through the contrast material from the superimposed unwanted information. The first few images in the sequence do not have any information about the blood flow, since the contrast agent has not passed through the vessels yet. These images are called mask images. When the contrast agent takes effect, resulting in the contrast-filled images, the unwanted background cancellation is achieved by subtracting a suitable mask image from a contrast-filled image [1].

One of the major problems encountered in DSA imaging is the presence of motion artifacts. When the mask image acquired prior to injection and the contrast-filled image acquired after the injection are not properly registered, then the subtraction of these images will not completely cancel the background but will produce structured noise. Such artifacts can lead to misdiagnosis or rejection of a DSA image sequence. In the latter case, the patient would have to retake the examination, which is invasive because it requires X-ray exposure, injection of contrast material, and catheterization. There are several approaches in currently available DSA systems to overcome the background motion [1], [2]. These approaches are a variation of simple shift or rotation operations on mask image to achieve a good registration. However, the motion artifacts are the combined effect of several factors and are more complicated.

The purpose of this paper is to present a new approach to motion artifact reduction using motion-compensated prediction.

II. Problem Formulation

The single mask subtraction DSA can be written as

$$d(m, n) = f(m, n, t_c) - f(m, n, t_m) \quad (1)$$

where t_c is the time index of the contrast image and t_m of the mask image.

If we assume that the patient has been slightly moved parallel to the film plane and there has not been any rotation, we could obtain a better quality subtraction

$$d(m, n) = f(m, n, t_c) - f(m - \Delta m, n - \Delta n, t_m) \quad (2)$$

if we could estimate the translation vector $\underline{D} = (\Delta m, \Delta n)$. The translation vector can be estimated by minimizing some cost function of the prediction error $d(m, n)$. This is in general a computationally involved problem because the cost is a nonlinear function of translation parameters. The dominant methods used for this task are known as block matching algorithms [4]. Finally, to improve performance we incorporate into the algorithms the ability to compensate for small rotation. This improves the performance because it can deal with more complicated types of physiological motions, e.g., breathing.

Another way to avoid blocking artifacts is to estimate the translation vector using pel-recursive algorithms, which avoid this problem by operating on a per pel basis. The algorithm we have chosen is the one developed by Bergmann [3]. This method converges very fast without presenting significant overshoots. It should be stressed at this point that since the goal and the operational requirements (e.g., no need for real-time operation) are different in video image coding and DSA we have emphasized performance rather than computational complexity when we selected and implemented the motion estimation algorithms.

III. Block Matching Algorithm

The first algorithm used for motion compensation is the *Displacement Estimation* method for block matching. The block matching technique is not computation intensive; therefore it is not as time consuming as some other algorithms. This method first divides the image into blocks. It then determines the displacement vector of each block of the current frame (current image) with respect to each block of the previous frame (previous image), finding the best match and minimizing the error. The displacement vectors, for each block, are used to describe the motion difference between each respective block of the current and previous frames. The block matching algorithm assumes that all the

pixels of one block have the same displacement vector. As in the example of two successive X-ray images, the displacement vector would describe any linear motion by the patient. The prediction error

$$PE(z_0, i, j) = \frac{1}{MN} \sum_{m=-\frac{M}{2}}^{\frac{M}{2}} \sum_{n=-\frac{N}{2}}^{\frac{N}{2}} |s_k(z_{mn}) - s_{k-1}(z_{m+i, n+j})| \quad (3)$$

is summed over the area of each block. The vector that provides the minimum error becomes the vector which predicts the motion of that particular block of the current frame. M and N represent a block that is $M \times N$ pixels whose center is z_0 . The current displacement vector is (i, j) and m and n are used to traverse the block from pixel to pixel giving the temporary new vector [5].

$$z_{mn} = z_0 + [\mathbf{m}, \mathbf{n}]' \quad (4)$$

There are several different ways to conduct a search through the block to choose a displacement vector. Some examples are the *2D-logarithmic search*, the *Conjugate search*, and the *Three-step search* procedure. The three-step search procedure will be explained because it minimizes searching time.

The three step search begins by dividing the image into blocks. Then, using three steps, the displacement vector for that particular block is found. In the first step, the procedure tests eight search points of predetermined displacement from the center point. The procedure then moves the center to the point which had the least error. In the second step, as in the first, the procedure tests eight search points. These points have a displacement from the new center point which is one less than in the previous step. The center is, once again, moved and the third step is executed. The third step is the same as the first and second, except the displacement is decreased once again. The new center point is determined, by way of minimum error, and the displacement vector is the vector which points from the original center of the block to the new center of the block after the three steps. The procedure starts anew for the next block of the image, and continues for all the blocks of the image.

In many cases, there is more than just linear motion between two images. Often times there is rotational motion also. *Rotational Block Matching* offers a way to predict any rotational motion. The idea behind Rotational Block Matching is that it predicts for translational motion in the same manner as the Block Matching procedure, then it predicts rotational motion by testing several predetermined angles of rotation for minimum error for each block. The vector which provides least error becomes the motion estimation vector for the block.

IV. Pel-Recursive Algorithms

In general, pel-recursive algorithms are algorithms which use a displacement vector, for each separate pixel, to predict the motion of the current frame with relation to the previous frame. The displacement vector designates the direction of motion of each pixel. Pel-recursive algorithms do not use the initial displacement vector. Instead, successive terms are added to the vector, using the gradient method, to make it more accurate.

$$\hat{D}_{i+1} = \hat{D}_i + U_i \quad (5)$$

where $\hat{D}_i$ is the current displacement vector, $\hat{D}_{i+1}$ is the updated displacement vector, and U_i is the update term of iteration [2]. The displacement vector is initially found by using

$$\hat{D} = \left[\begin{array}{ccc} \sum DIF_e^2 & \sum DIF_e & \sum DIF_l \\ \sum DIF_e & \sum DIF_l & \sum DIF_l^2 \end{array} \right]^{-1} \left[\begin{array}{cc} \sum DIF_f & \sum DIF_e \\ \sum DIF_f & \sum DIF_l \end{array} \right] \quad (6)$$

DIF_f is the difference in intensity from one image to the next (Frame difference). DIF_l is the difference in intensity of one pixel with the pixel directly below it (Line difference). DIF_e is the difference in intensity of one pixel with the pixel next to it (Element difference) [3]. Using $\hat{D}_i$, the displaced frame difference

$$DFD(x, y, \hat{D}_i) = s_k(x, y) - s_{k-1}(x - \hat{d}x_i, y - \hat{d}y_i) \quad (7)$$

where s_k is the intensity at point x, y , and $\hat{d}x_i$ and $\hat{d}y_i$ are the x and y components of the displacement vector, $\hat{D}_i$, [2].

One recursive displacement estimation algorithm of considerable interest is the one developed by Bergmann. Bergmann used the average of two second-order derivatives in the denominator. Approximated equation

$$\hat{d}x = \frac{E[DIF_f(x, y) \cdot \partial s(x, y) / \partial x]}{E[(\partial s(x, y) / \partial x)^2]} = \frac{\sum(DIF_f \cdot DIF_e)}{\sum(DIF_e^2)} \quad (8)$$

is used to give the x component of the displacement vector, $\hat{D}$.

Minimizing the average of the square of the displaced frame difference is the same as maximizing the cross correlation

$$R_{s_k s_{k-1}}(x, y, D) = E[s_k(x, y) \cdot s_{k-1}(x - dx, y - dy)] \quad (9)$$

Using (8), (9), gives Bergmann's resulting equation

$$\hat{dx}_{i+1} = \hat{dx}_i - \frac{\frac{\partial}{\partial x} r_{s_k s_{k-1}}(x, y, \hat{D}_i)}{\frac{1}{2} \left[\frac{\partial^2}{\partial x^2} r_{s_k s_{k-1}}(x, y, \hat{D}_i) + \frac{\partial^2}{\partial x^2} r_{s_k s_{k-1}}(s, y, 0) \right]} \quad (10)$$

V. Experimental Results

In order to demonstrate this new approach to DSA image enhancement, we used actual patient data containing several sequences of 512 x 512 images. The number of images in each sequence varied from 12 to 16. The resulting enhanced images were adjusted to the range of display device. Results comparing the performance of the proposed techniques have been obtained and show a significant improvement over the traditionally used methods, as shown in Fig. 1.

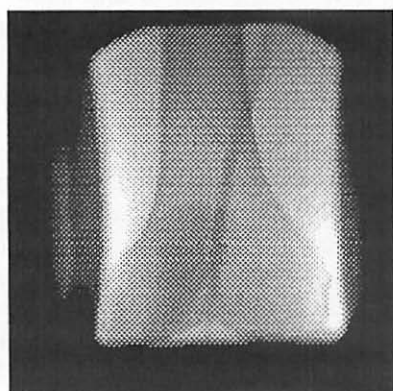
VI. Conclusions

The pel-recursive algorithm is preferable over the block matching algorithm because it consistently produces a much more intelligible image. The quality of the subtracted image might be improved by increasing the number of iterations performed on the displacement vector. If there is not enough time to use the pel-recursive procedure, the block matching technique is a good alternative algorithm. If different block sizes are experimented with, an image of substantial clarity can be produced. Further work regarding combining block matching with rotation is underway.

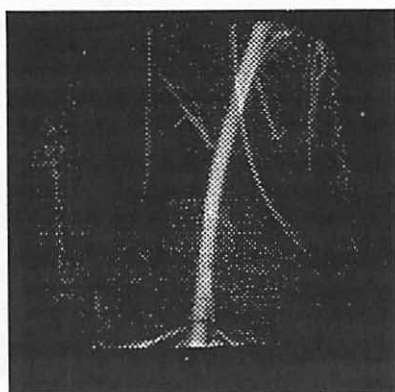
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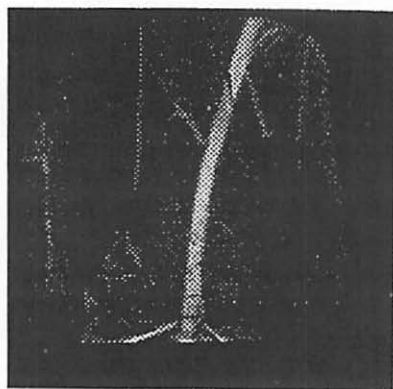
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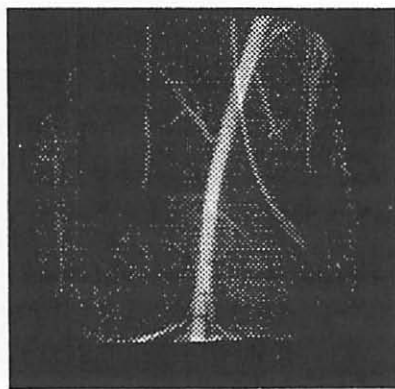
(a) mask image



(b) single frame subtraction



(c) block matching



(d) pel-recursive subtraction

Figure 1. Digital subtraction angiography

Free Adjustment of Window Width and Level at a CT Workstation: Differences Between Readers and Image Variation

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We examined readers' window width and level choices during CT evaluation of diffuse lung disease with free adjustment of window width and level. Six readers each evaluated 28 cases of diffuse lung disease and 8 normal cases presented on a Sun 4/260 workstation. Readers used 5 category confidence scales to evaluate the visibility of fine lung structures and the presence of abnormalities. Free adjustment settings were quantified by calculating minimal and maximal window and level settings as well as the final window width and level setting chosen.

Analysis of variance showed that readers, not images were the most significant source of variation in window width and level settings ($p < .01$). The effects of images upon level settings were correlated with differences in the modal value of the image histograms in the lung region. Readers partially compensated for these differences by viewing denser images at higher levels. Correlations of window width and level setting showed that readers act to manipulate contrast without radically altering the appearance of the lung field.

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Introduction

The digital workstation gives the radiologist greater control over the way images are viewed than hard copy. Image contrast and brightness control can be exercised by adjustment of window width and window level at the workstation by the reader. Hard copy is typically viewed in a fixed window which is suited for a particular class of images without accounting for image variation within that class of images. Free adjustment of window width and level allows individual image sets to be optimized.

We were interested in how readers use free window width and level adjustment in CT evaluation of diffuse lung disease. As part of a

larger study evaluating the diagnostic benefits of free adjustment¹ we monitored the values of window width and level used by readers during evaluation of computed tomographs. The images were chest CT images, the majority of which exhibited subtle signs of diffuse lung disease.

Methods

Images were displayed on a Sun-4/260 workstation with a TAAC graphics accelerator board and a Trinitron monitor. The display consisted of two images per case presented side by side. Each image measured 15 cm by 15 cm and was presented at full 512 x 512 pixel resolution. Image window width and level were determined using full 10 bit contrast information. All images appeared initially in a lung window (2000 H.U., -500 H.U.). Adjustment of window width and level was accomplished by moving a mouse controlled cursor either up/down (width) or left/right (level) in the image window while holding the center button down. Window width and level changes were essentially instantaneous. In an initial introductory session all readers became familiar with the equipment and procedures.

The cases consisted of 28 with diffuse lung disease and 8 normal cases. For each case both standard computed tomography (CT) and high resolution computed tomography (HRCT) were available. This resulted in 72 sets of image pairs for the 36 cases. Six readers (three residents and three attending physicians) each viewed 18 CT image sets and 18 HRCT images sets twice over six sessions. Each case was viewed once in a fixed lung window (2000 H.U., -500 H.U.) and once with free window adjustment. Individual readers were paired such that if one viewed the CT for a case, another saw the HRCT. In three of the sessions, all of the images appeared in a fixed lung window and in the other three the reader freely adjusted window width and level. CT and HRCT images were randomly mixed together in a session. The order of fixed and free adjustment sessions was counterbalanced across readers.

Readers verbally evaluated cases using confidence scales to describe the presence or absence of a fixed set of normal and abnormal features. These responses were recorded by an experimenter. The computer would record all changes made to window width and level as well as the time at which the adjustment was made. This raw data was converted into a number of dependent measures. These included the narrowest and widest window width displayed for at least one second as well as the final window width setting chosen for the verbal evaluation. Equivalent level measures were also determined; narrowest and widest as well as final level chosen. Window width measures were highly intercorrelated as were level measures. We will limit the present discussion to the final window widths and levels chosen.

Results

Overall final window width and level settings showed that readers preferred narrower windows ($t = 5.29$, $p < .01$) set to lower levels ($t = 4.35$, $p < .01$) than the fixed lung settings provided. The average of final window width and level choices for each reader are shown in figure 1. The equivalent data for each case are shown in figure 2.

An analysis of variance was performed with observer, case and image type (CT or HRCT) treated as factors. Observers were a significant source of variation in window width and level settings ($p < .01$) while cases and image type were not.

For each image we calculated a histogram and then determined the mode of the histogram in the -950 H.U. to -400 H.U. range. Using this variable as a covariate in the analysis of variance, we found that most variance due to cases and modality was accounted for by this covariate, while as expected a substantial effect of reader remained.

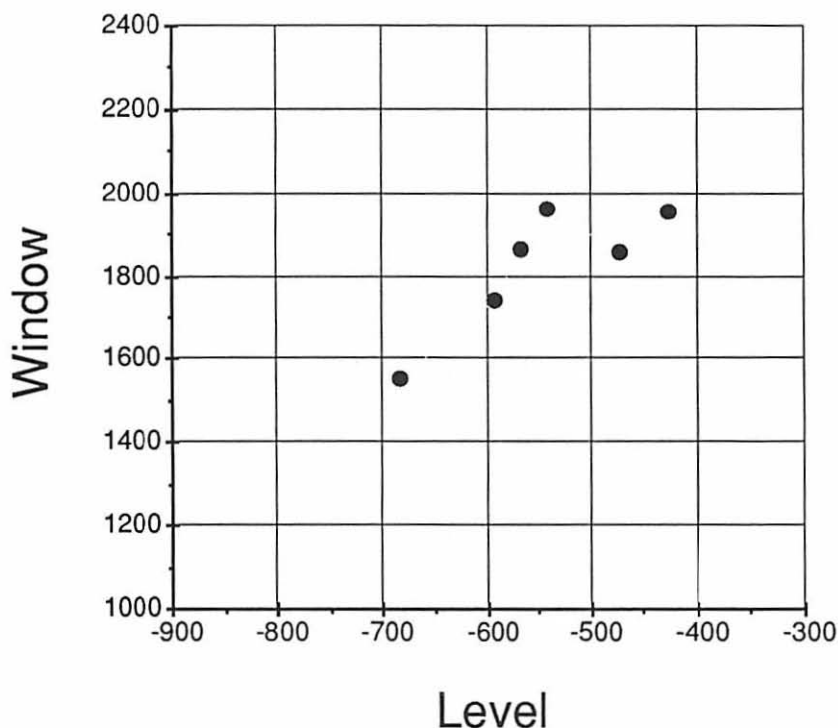


Figure 1. Window width and level settings for each reader, averaged across all cases.

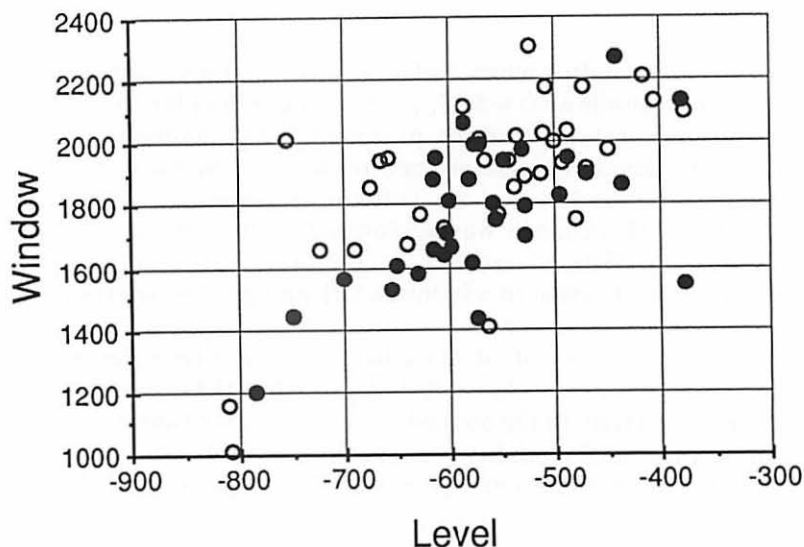


Figure 2. Window width and level settings for each case averaged across readers. Filled circles; CT, open circles; HRCT.

Table 1 shows the correlation of histogram mode, final window width setting, and final level setting. The image histogram only affects the level chosen, with lower levels corresponding to lower values of the histogram mode. Final window and level settings are correlated, with lower levels strongly correlated with narrower windows, but the final window setting is not related to the image histogram. One aspect of the correlation of final window width and level settings is obvious from figure 1. Readers who on average view images at lower levels, view the images in narrower windows.

Table 1. Correlation of histogram, final level, and final window

	Final Level	Final Window
Histogram	.35	.06
Final Level	---	.63

In order to understand the implicit strategies of individual readers in choosing final window width and level settings, we calculated the regression line relating final level chosen to histogram mode, and final window chosen to final level chosen on a reader by reader basis. Table 2

shows the results of this analysis.

Table 2. Slope and intercept of regression lines for final level setting

	Histogram		Final Window	
	slope	int	slope	int
Reader 1	.63	-660	.09	-728
Reader 2	.51	-517	.14	-692
Reader 3	.12	-607	.24	-1034
Reader 4	.73	-732	.26	-1043
Reader 5	.64	-587	.22	-902
Reader 6	1.12	-893	.17	-965

On a reader by reader basis we calculated the multiple regression of final level setting with the combination of histogram mode and final window setting. Multiple r was significant for all readers, and varied from .63 to .84. Thus from 35 - 70% of individual reader's variation in level setting was explained by these two variables.

Discussion

The greatest single factor affecting window width and level setting in this study was the reader who made the adjustment. As figure 1 illustrates, some readers choose higher levels and wider windows, while others choose lower levels and narrower windows. We feel these differences probably reflect a preference for different degrees of image contrast by different readers.

A reader's level setting is partially determined by intrinsic image characteristics as reflected in the histogram of the image. The reader sets a level which tends to compensate for the variation in the density distribution within the lung and the distribution of pixel information in the image, but this compensation is generally not complete (except for reader 6, for whom the slope of the regression line in table 2 exceeds 1.0).

There is another factor which contributes to level setting. Although the image histogram has negligible effects upon the final window setting, window and level settings are related. This correlation may represent a coordination of width and level setting which allows the reader to adjust contrast gain while keeping the brightness of parts of the image fixed. From the data in table 2, we calculated the average slope (.19) and the average intercept (-894) of the regression line describing the

relationship between window width and level choices. From each solution to this equation, a function which describes the mapping of CT densities to workstation grey levels can be calculated. Some of these lines are shown in figure 3. It can be seen that lines converge to map the region between -900 - -700 H.U. into the second quartile of workstation grey levels. This information from the region where parenchyma of normal lung is to be found during inspiratory breath holding² is clearly essential to the evaluation of the lung. These transformations tend to cause this region to appear at a constant brightness despite changes in image contrast.

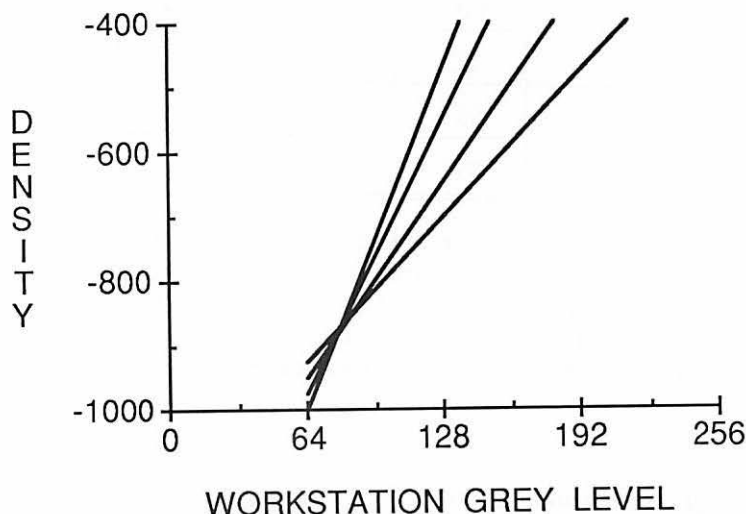


Figure 3. Family of width and level settings map density to grey level

It appears then that both individual preferences and image characteristics contribute to free adjustment of window width and level.

Free adjustment of window width and level is regarded by radiologists as a useful function of CT display monitors.^{3 4} In the present experiment however, free adjustment did not increase reported visibility of fine lung structures or increase diagnostic accuracy.¹ While the effect of window width on detectability of features has been demonstrated with hard copy, there is little data available on the diagnostic utility of free adjustment.

There is a demonstrated cost to free window adjustment. In this experiment readers took 25% longer to evaluate cases with free adjustment. Free adjustment is clearly a time and attention consuming ancillary task which potentially may interfere with the readers primary diagnostic task.⁵ An alternative to free adjustment which does not

demand the reader's time or attention is automatic adjustment of window and level by the workstation. A number of plans and algorithms for automatic window width and level adjustment have been described.⁶

The activities of the readers in adjusting window width and level appear to be sensibly described as adjusting contrast while tending to keep structures of interest within a certain range of brightnesses. One suitable goal of an automated windowing algorithm would be to produce window width and level settings that parallel the settings of a reader free to adjust the window. The above results suggest that such an automated system would need to account not only for image characteristics, but also differences in image preferences between readers. Such a system could easily be realized on a workstation, where readers identify themselves. If window width and level settings were recorded, reader preferences could be profiled and image contrast preferences anticipated, freeing the reader for the more critical clinical tasks.

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2D and 3D Display of Aneurysms from Magnetic Resonance Angiographic Data

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ABSTRACT

This paper describes techniques to visualize aneurysms, dilated arteries and aneurysm balloons in two and three dimensions from Magnetic Resonance Angiographic data sets to aid physicians and radiologists in brain aneurysm treatment and surgery planning. Brightest Pixel Method using ray tracing is implemented to highlight the aneurysm in 2d. SVVC (segmentation via voxel connectivity) supports the recognition of the blood vessels and aneurysms and presents them in 3d. Rendered images are generated to provide realistic visualization.

Key Words: Magnetic Resonance (MR), Aneurysm, Blood Vessels, Connectivity, Rendering, Quantitative Analysis, Image Processing, Visualization.

I. INTRODUCTION

Aneurysms are dilated arteries subject to rupture, these malformations are life threatening. They cause brain damage if not surgically corrected. The objective of this paper is to describe methods for visualizing and modelling complex structures from 3d volumetric data sets of Magnetic Resonance Angiography for presurgical planning.

Since the introduction of magnetic resonance (MR), computed tomography (CT), and photon emission tomography (PET) in clinical medicine, the importance, evaluation and interpretation of both cross-sectional and three-dimensional anatomy has significantly increased. The visualization of cross sectional anatomy coupled with image processing, graphics and mathematics allow hidden information to be extracted. A number of approaches^{1,2,4,5,6,7,16,17} have been developed to visualize volumetric data sets. Attempts have also been made^{3,8,11} to visualize the internal details of brain anatomy. Volumetric images can be better viewed if hidden objects are rendered. A problem in 3d rendering is "obscurity". To display complex anatomy, researchers¹⁸ have attempted to find the object contours of a region of interest (ROI), create wire frames, and then render the object. This process is very difficult to formalize, for example, if part of the object is not visible in some slices, if slices have multiple objects in them, etc. Attempts have also been made to solve such problems using knowledge based systems¹⁹.

II. IMAGE PROCESSING FLOW

(i) Image Processing Flow for the MRA slices:

The flow has been divided into three stages: Data Acquisition, image processing coupled with graphics, and animation. Magnetic Resonance Angiographic images are ported from the GE Signa 1.5 Tesla, in a 256 x 256 matrix. Two-dimensional ray casting schemes are developed to visualize the aneurysm and the dilated arteries. For three-dimensional viewing, two methods are used: rendering of the surface data sets and the Segmentation Via Voxel Connectivity (SVVC). Three dimensional views are developed in x, y, z and arbitrary directions are selected for the visualization of the dilated arteries and aneurysm balloons. Magnetic Resonance Angiographic data were processed on several patient studies including healthy and disease cases. To optimize the features of blood flow and the aneurysm, specific acquisition parameters were used. Some researchers^{10,20,21} have discussed this issue in great depth (e.g., effect on the pixel intensities due to the slower laminar blood flow, effect of the speed of the blood on the pixel intensities). Different types of MRA data were acquired to compare the results of the connectivity algorithm.

(ii) System libraries with X windows on RISC:

The hardware used for the 2d and 3d display is the IBM's RISC/6000 work station and the 6091 display system with 4.3 bsd Unix OS using X window with graphics libraries. The functions implemented included thresholding, zooming, rendering, segmentation and animation.

III. 2-D DISPLAYS

The steps in the two dimensional display of the aneurysm data were as follows: Brightest Pixel Method, also called Maximum Intensity Projection (MIP). In this algorithm, we generate a 2d image from the complete volumetric data sets by selecting the maximum intensity signal. We have generalized the presentation to provide any desired plane of projection. The desired plane of projection is specified and the rays are cast through the voxels perpendicular to each image pixel. The casted ray is the trajectory of that path. The projected image pixel is the pixel with a signal strength equal to that of the voxel with maximum intensity (brightest voxel) lying along this trajectory path. This procedure is repeated for all the image pixels in the selected projection plane. An enhanced version of the MIP would be to restrict the ray casting to a volume of interest (VOI). The blood vessels (flowing material) and tissues (stationary material) both exist in MRA data. To better separate them, we try to eliminate the stationary material by concentrating only on the VOI. This can be done by looking at the three orthographic projections. A capability is provided to mask slices if particular slices or slice regions are not of interest.

IV. 3-D DISPLAYS

(a) SVVC (Segmentation Via Voxel Connectivity)

Researchers are developing techniques to segment 3d regions of interest into meaningful regions or objects for quantitative analysis. We have attempted to segment the aneurysm and blood vessels from different tissue types and lesions. The interaction can be done by the user to segment these VOI zones using morphological operators²² (or morphological filters). In our case the segmentation has been done using connectivity of voxels (SVVC). We need to identify objects which lie above a specified threshold signal intensity and which are connected as nearest voxel neighbors within the 3d volume. The threshold is chosen to eliminate the blood vessels from the stationary material like tissues. The threshold value depends upon the data sets taken, but it is usually 2 to 3 sigma from the mean value. We thus

highlight the blood vessels of interest and exclude other regions.

(b) Rendering

Depth Cueing supports the interpretation of the 3d data. This image can be produced by imaging the negative distance of the visible voxels to the observer. To provide realistic images, surface normal vectors need to be calculated. Some researchers^{9,16} have used the depth factor to distinguish surfaces at different locations. For calculating the surface normals, z-buffer gradient shading⁹ is a computationally efficient method. While casting rays on to the data sets from any view point, we locate the surface of the vessels i.e., the distance of the surface vessels from the volume data edge (in the z-buffer). Given the z-buffer, $Z(x,y)$, components of the surface normal are approximated from the gradient⁹ vector (Del_z).

$\text{Del}_z \approx (\partial z/\partial x, \partial z/\partial y, -1) = (x_p, y_p, z_p)$, the partial derivative $\partial z/\partial x$ is approximated as the weighted sum of the backward and forward differences of the neighboring pixels in the z-buffer.

$$\partial z/\partial x = W(|d_f|) \text{Sign}(|d_f|) + W(|d_r|) \text{Sign}(|d_r|);$$

$$W(d) = \pi/4 (d-a/b-a), \text{ if } a \leq d \leq m \\ 0, \text{ otherwise.}$$

$$d_f = Z(x, y) - Z(x-1, y),$$

$$d_r = Z(x+1, y) - Z(x, y); \text{ where } m \text{ and } a \text{ are selectable parameters and } d \geq 0.$$

The computation of $\partial z/\partial y$, d_r , d_f is similar. The resulting spherical vector is converted to cartesian coordinates. Once the surface normals are calculated, we can use the standard Phong Shading model for rendering. In that case, the value of the surface voxel can be given as:

$$S(x,y,z) = K_a + K_d * (L \cdot N) + K_s * (R \cdot V)^n * (1-K),$$

where:

$S(x,y,z)$ = surface element at (x,y,z) .

K_a = fraction of ambient component of light, taken to be 0.

K_d = fraction of diffused component of light, taken to be 0.8.

K_s = fraction of specular component of light, taken to be 0.2.

We use $a=0$, $m=8$, and $b=10$.

K = depth factor, taken to be 0.7.

n = exponent for the modelling highlights, taken to be 5.

N = surface normal vector at location (x,y,z) in direction of light source.

L = normalized vectors in direction of light source.

V = normalized vector in the direction of the observer.

R = reflection vector.

$\cdot$ = dot product.

(c) Implementation of Mathematical transformations

Once the SVVC algorithm is applied to the slices or 3d surface rendering is done, then 3d mathematical transformations are performed to show all the animated views of the blood vessels and aneurysms. This involves pushing the initial matrix of the 3d blood vessels and aneurysms over the stack, and later popping this matrix when the second view is shown. Double buffering is used for this operation. Depth cueing is also performed before it pops and pushes into the mathematical stack for new transformations. Color range is set to provide realistic views.

V. EXPERIMENTAL RESULTS

Figure 1 shows the original MRA slices of the normal patient. Figure 2 shows the original MRA slices of the abnormal patient: cross sections of the aneurysm and

dilated arteries and veins are visible. Figures 3 and 4 show the zoomed version of the slices, Figure 5 shows the aneurysm location in a oblique cut section, Figures (6 and 7) shows the blood vessels using BPM in normal and abnormal case, Figure 8 shows the 2D display of vessels using MIP, ray casted from top, Figure 9 shows the segmentation of vessels from the tissue, Figure 10 shows the surface rendering in 3d using Z buffer, Figure 11 shows front view of the blood vessels using SVVC, Figures (12 and 13) shows clearly the aneurysms and blood vessels symmetric about the center using SVVC, and Figure 14 shows the zoomed version of the aneurysm extracted out of MRA data set.

VI. CONCLUSIONS AND DISCUSSION

SVVC (Segmentation via voxel connection) is an effective technique for viewing MRA data sets in a three-dimensional form. Surface rendering from the z-buffer algorithm provides improved visualization but the problem of obscurity is not resolved. There is no general solution of the visualization of very small objects such as blood vessels from Magnetic Resonance Angiographic Images. IMF (interactive morphological filtering) is helpful. Factors which aid the visualization process are high contrast images and high circulation of blood flow in the arteries and veins.

VII. APPLICATIONS

Quantitative application of the segmented data sets in three dimensions would help the radiologist and surgeon in the planning of surgery. Some of the applications in progress are, 3d fractal dimensional analysis of the segmented arterial tree. This involves the tracking of the three-dimensional blood vessels using tracking algorithm and implementing regression analysis to find the fractal dimension. Distances between various aneurysms are calculated for the geometric modeling. Locations and orientations of these aneurysms provides support for surgical planning.

VIII. ACKNOWLEDGEMENTS

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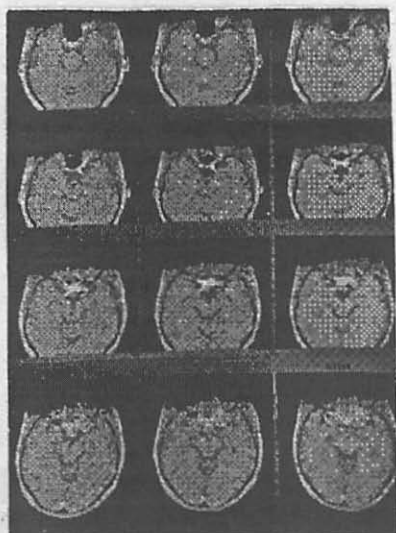


Fig1: Cross sectional slices of MRA data set for the normal patient

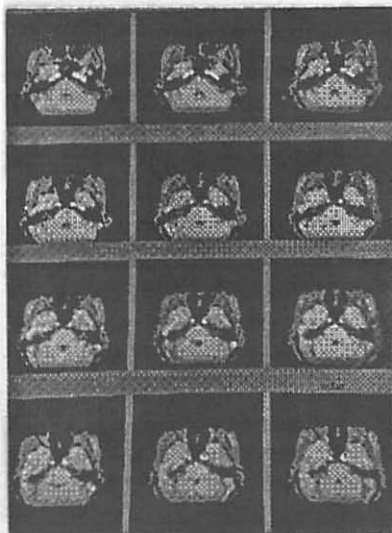


Fig2: Cross sectional slices of MRA data set for the abnormal patient



Fig 3: Zoomed version of the normal MRA patient slice



Fig 4: Cross section of the aneurysm seen in the zoomed version of the abnormal MRA patient slice

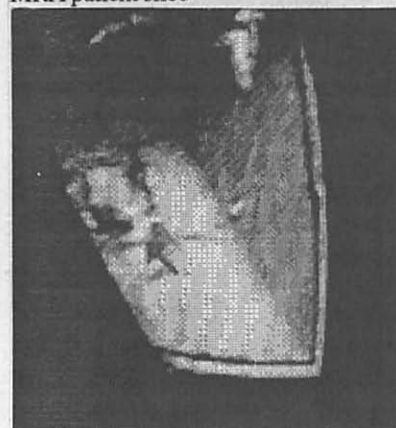


Fig 5: Oblique cross section of the complete data set to show the position of the Aneurysm

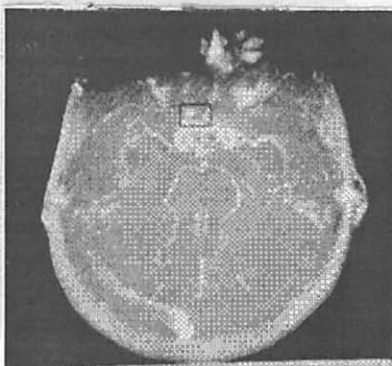


Fig 6: Vessels shown using Maximum Intensity Projection in the 2d case



Fig 7: Vessels shown using BPM in abnormal case (2d)



Fig 9: Segmentation of the vessels and aneurysm from the tissue of the side 2d MIP.

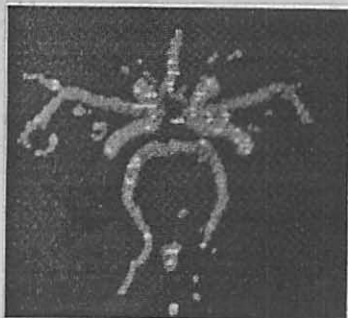


Fig 11: Front View of the vessels and aneurysm using SVVC(3d).



Fig 13: Dilated Vessels symmetric about the center (180° inverted to fig 12) using SVVC

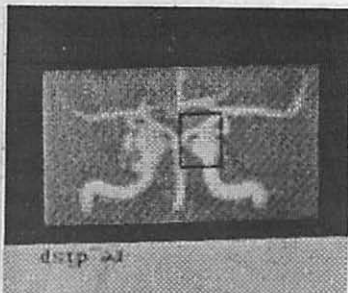


Fig 8: MIP or BPM of the top view of the MRA data set

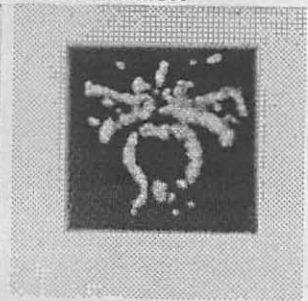


Fig 10: Surface rendering of the vessels using Z Buffer gradient algorithm (aneurysm area not known)



Fig 12: Dilated vessels shown on the left and right side of the center, shapes like a balloon (Aneurysm)



Fig 14: Aneurysm balloon shape extracted in 3d (zoom) case using SVVC from MRA data

SESSION 18

**U.S. Army/Air Force
MDIS Project**

*Chair: Lt. Gen. Quinn H. Becker,
USA, M.C. (ret.)*

Preparing a Request for a Whole Hospital PACS

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INTRODUCTION

The introduction of a whole hospital PACS involves a series of stages, namely: 1. An indication and appreciation of the potential benefits of PACS, 2. the strategic context of PACS in relation to the development of the hospital, 3. the constraints within a particular hospital, 4. the consideration of an option appraisal and carry out an economic analysis of the preferred option, 5. the preparation of a technical and functional specification for a whole hospital PACS, 6. the procurement process and selection of a preferred supplier, 7. conformance testing of the system, and 8. Management of the implementation.

It is assumed that items 5-7 will be covered in the parallel paper prepared by Dr. Siegal.

Potential Benefits of PACS

Most of the anticipated benefits of PACS, which have been well documented in the literature, will only be achieved from systems with a modern performance specification. Many operational systems utilize inadequate PACS technology, using workstations of poor brightness and resolution, and a slow response. The technology continues to improve, and it is anticipated that the expected benefits, combined with satisfactory performance, will be achieved with equipment currently available.

THE OBJECTIVES AND CONSTRAINTS

The Objectives

The objectives of installing PACS are:- 1) To enhance the clinical and economic efficiency of the hospital, 2) to make more effective use of

the hospital staff and resources, 3) to enhance the efficiency of the diagnostic imaging service and 4) to distribute both the diagnostic images and associated reports rapidly throughout the hospital.

The constraints of the proposed installation of PACS are:- 1) To provide satisfactory levels of diagnostic services within the currently available revenue resources and 2) to meet the teaching requirements of the department and hospital.

The Range of Options for Consideration

The options which are considered usually relate to:- 1) A partial digital system serving the x-ray department only, and 2) a whole hospital PACS which allows the hospital to operate as a filmless hospital.

Implementation of a Partial PACS System

The introduction of a partial PACS system in several centres, is being used as a learning process to become familiar with the techniques and limitations of the new technology. These systems have usually been developed within the CT and MRI scanning sections of the radiology department.

This approach involves the simultaneous operation of two operational procedures, one based on film and one based on electronic images. It provides the advantages to the radiology department only. The main disadvantage of this approach is the high revenue costs of the operation of both old and new technology. The experience thus gained with a lower capital outlay, is more than offset by the higher revenue consequences of the introduction of a partial system.

OPTION APPRAISAL - THE USE OF AN ECONOMIC MODEL

A detailed economic model based on that described by Saarinen¹ has been used to analyse the economic viability of various options. The conclusions of the economic analysis clearly indicates that a partial PACS system is not a viable long term economic option.

Hospital Wide PACS System

Revenue Costs

The direct revenue consequences arise mainly from the cost of

the staff working within the department, i.e. the medical staff, radiographers, dark room technicians, nursing staff, secretaries, porters, record and filing clerks. It also includes the costs of consumables, such as film and chemicals, film envelopes, cassettes, screens, catheters, swabs, syringes, contrast media, drugs medication etc., equipment servicing costs, maintenance contracts, and any other administrative costs associated with the department.

The maintenance costs anticipated for a full PACS installation is estimated at approximately \$750,000 per annum. This would be partly offset by the reduction in maintenance charges on conventional equipment. There would be a net saving on the maintenance cost of the conventional x-ray items.

The savings on film and chemicals, (95% of the current cost) are dependent on the local costs and the local workload.

The use of digitised chest unit and the introduction of re-usable medium, would allow a reduction of radiographer staff, file room clerks, and porters. There would be additional staff required to manage and oversee the complex computer system and be responsible for the housekeeping and back-up tasks associated with the system. There is a net saving on staff, compared with the cost of a conventional department.

There would be some additional consumable costs (magnetic discs, optical discs and optical tapes). There would be a net decrease in the consumable costs, with reduced usage of paper and film folders being partly offset by the usage of magnetic media.

There is a net additional cost of the whole hospital option. If the cost benefit derived from the use of the vacated space is excluded, the net effect of the introduction of PACS is a net increase in revenue cost of approximately 1.5% per annum.

Indirect Financial Benefits Resulting from PACS

The cost savings arising from indirect benefits are discussed below.

Saving of Junior Medical Staff Time

Some of the areas of achievable improved efficiency are readily quantifiable, such as in the preparation of films by junior medical staff

for joint radiological sessions, whilst others are less easy to quantify, such as avoiding errors caused by misfiled films. The saving of junior medical staff time in procuring and preparing films for departmental clinics has been estimated as equivalent to 5 whole time equivalents.

Increase in Staff Efficiency

A notional sum has been estimated for the improvement of efficiency of the radiological staff (15%) and the minimum value of this improvement calculated as 15% of the labour costs. An assumed increase in non-radiological medical staff efficiency of 2% is estimated.

Ward and Clinic Clerks

A substantial part of the activities of ward and clinic clerks is associated with the organisation and handling of x-ray film envelopes of patients on the wards and attending the outpatient clinics. The daily transport and sorting of the very large number of film envelopes will no longer be necessary with the introduction of PACS. An improvement in efficiency of 25% of the hospital and ward clerks has been estimated.

Decrease in Unnecessary Examinations

Part of the enhanced efficiency of the department, will arise from the reduced number of reject radiographs achieved by the use of re-usable medium, and the reduction in the number of repeat requests, due to the rapid availability of images of previous investigations. This improved efficiency will be reflected in the reduction of the number of repeat examinations and in the number of unnecessary investigations.

Reduction in Length of Stay

If a minimal reduction of length of stay were achieved by the re-examination of operational procedures due to the introduction of a filmless hospital, then this is equivalent to the significant reduction in cost of hospital operation which has been conservatively estimated at 0.5% of the hospital operational cost.

The Redesignation of Acute Beds as Five Day Beds

In an attempt to achieve the direct benefits of utilising the improved hospital and radiology department efficiency, the concept of providing beds which would be used primarily for patients awaiting or recovering from radiological investigations or procedures and be located

as a group in a non-acute environment was proposed. These beds would be retained within the agreed complement of the individual medical firms, and be "medically serviced" by their medical staff. In order to ensure the full utilisation of the early availability of reports and images, it is essential that the hospital discharge policies and procedures are adjusted to take full advantage of these changes in operational pattern.

ACCUMULATED COSTS, SAVINGS AND BENEFITS

Assumptions

An annual increase in workload is assumed. This is reflected in an increase in film costs and storage space requirements and is superimposed on the inflationary increase in film costs. Labour costs and the cost of equipment maintenance are assumed to rise in line with inflation. The cost of building space is included. This factor is applied to the space created by the eventual abolition of the requirement of space for a film store. The value of the space released for other uses within the hospital has been costed at a conservative 60% of the current real cost of "building from new".

DIRECT COSTS/SAVINGS

These direct costs/savings relate to capital, labour, archive materials, operational costs and maintenance. The capital costs comprise the PACS components, i.e. work-stations, networks, image and data management systems and interfaces.

INDIRECT COSTS/SAVINGS

The indirect costs/savings relate to unnecessary investigations, junior medical staff, radiology and radiography staff, medical staff, clerical staff, re-designation of beds, and reduction in length of stay.

RESULTS OF APPLICATION OF THE MODEL

The cumulative discounted cash flow indicates that the net present value (NPV) goes negative between nine and ten years after the start of the project. The contribution of the indirect savings is an essential factor in achieving a justifiable investment decision. Many of the assumptions within the model which produced this conclusion are very conservative. The assumed life of the equipment is 10 years after the project "goes live". Sensitivity tests have been carried out on the

variables of the model. The annual maintenance cost is significant, together with the potential improvement in medical staff efficiency.

DISCUSSION

The economic analysis of the hospital PACS installation is based on the conservative interpretation of a realistic model. The results derived from it depend on the reliability of the assumptions and the ability of the management to implement the operational changes to ensure the recovery of the direct cash benefits.

Since the capital is incurred early in the implementation process, any reduction in cost of the equipment crucially affects the economics of the project. It is possible that as the technology continues to improve, especially in workstation cost and performance, the capital cost of the equipment may reduce. This can only be tested against a formal response to a detailed specification of the system.

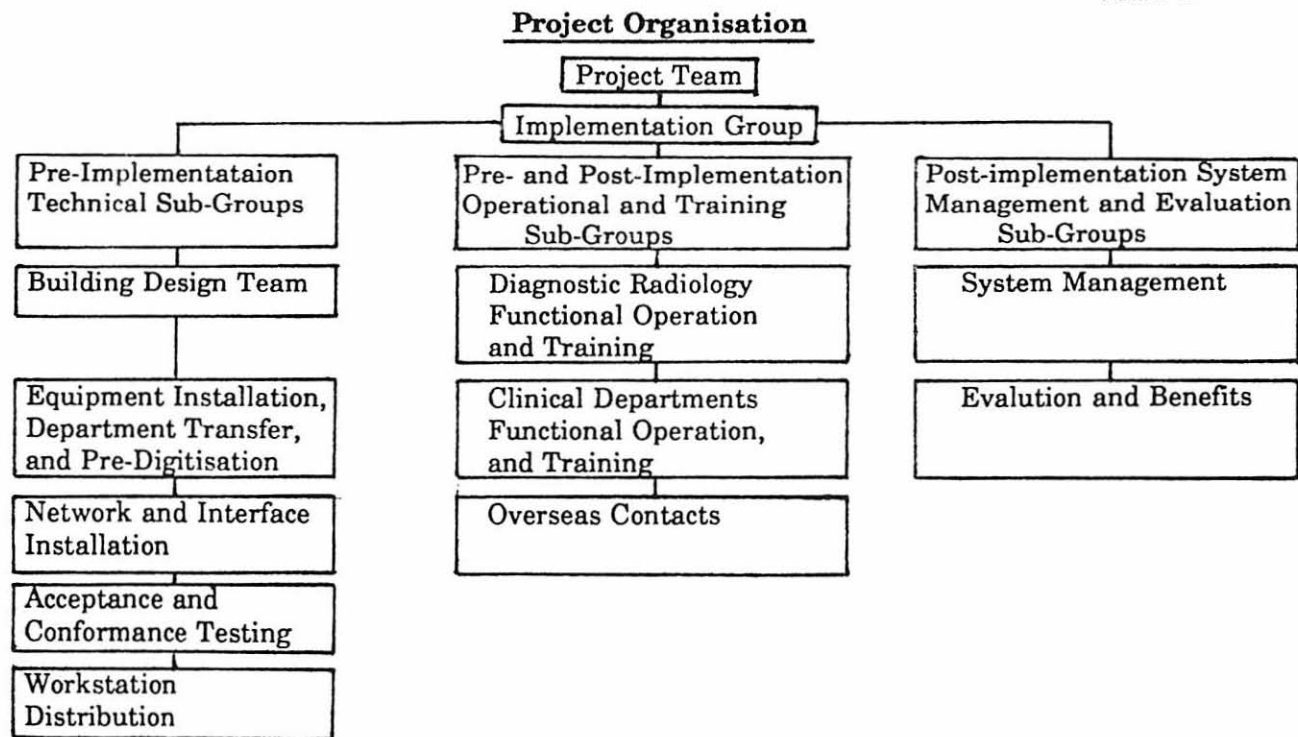
What clearly emerges from the study is that it is very unlikely that PACS could be economically justified purely on the basis of direct cost savings. The result in terms of pay back period is slightly longer than that reported by Saarinen et al. However the continuing benefits in quality of service to patients, and qualitative improvement in the imaging service indicate that the investment in PACS to be worthy of serious consideration.

ORGANISATION OF A PACS IMPLEMENTATION TEAM

The Hammersmith PACS project works under the direction of a Project Team. This Project Team receives reports and proposals from an Implementation Group, which comprises the Chairmen of various task sub-groups which are concerned with: 1) technical, 2) operational and training, and 3) evaluation tasks, as indicated in Table 1. These sub-groups are concerned with pre and post-implementation tasks which involve discussion and consultation with a wide range of hospital administrative, nursing and medical personnel. The principal tasks are self explanatory from the title of the sub-groups.

¹Saarinen, A.O., Haynor, D.R., Loop, J.W., Johnston, L., Russell, J., Mitchell, K., and Nemerever, M., Modelling the Economics of Pacs; What is important? SPIE Proceeding, Vol. 915, Medical Imaging III, Newport Beach Feb. 1989.

Table 1



Posters

Imaging of Radiation Field Pattern in Photomedicine

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Introduction

Interaction between electromagnetic radiation in the visible range and biological tissue has become a field of interest in biological investigation during the last years. The impetus seemed to be originated by new problems arising in noninvasive clinical research as well as by recent developments in photodynamic therapy. Although differences in absorption of light depend in a distinct manner on tissue properties its practical application is limited by the high scattering coefficient in tissue, especially Raleigh scattering on protein molecules and Mie scattering on cells. Radiation characteristics may be studied by use of transport equation but it must be considered that absorption and scattering coefficients are difficult to determine and, moreover, change within physiological or pathological conditions. In this study we use low-frequency modulation of laser noise to determine metabolic and structure effects within the tissue. The principle is outlined in Fig.1 where two light paths are depicted. Assuming that on way 2 light has to penetrate a different tissue structure in contrast to way 1 this will result in the occurrence of a new noise source. It is therefore necessary to measure the statistical relationship of the signals between two points, which is performed by computation of the coherency.

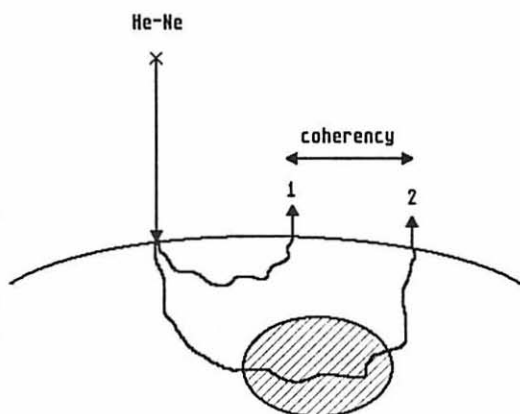


Fig. 1

Methods

The high absorption of light in tissue demands for sensitive conversion from optic to electric qualities with an high signal to noise ratio. A transimpedance amplifier will meet our purposes since it may be designed

for high sensitivity¹ and for clinical purposes it is superior to photomultiplier and exhibits a higher quantum efficiency. The amplifier consists of two stages. In the first which is primarily responsible for sensitivity a pin diode is used and dc and ac components will be separated in the second stage. Therefore at the end of the arrangement only time dependent changes in light are proven. In the following light from a 15 mW He-Ne laser was used. For further analysis samples of 2 seconds duration are analog to digital converted with a Nyquist rate of 512 s^{-1} and 12 bits amplitude range. Subsequently a Digital Fourier Transform is applied according a radix 2 algorithm. For suppression of leakage effects and to perform a consistent spectral estimate a Parzen windowing is used

$$W(f) = 0.75 * M * (\sin(\pi * f * M / 2) / \pi * f * M / 2)^2$$

with frequency f and M =sample duration/2. We used a frequency smoothing rather than a smoothing in time, with a Parzen window which is best suited for coherency computations since it does not affect the semipositive definiteness of the covariance matrix². Let denote s_1 and s_2 the power spectra in point 1 and 2 respectively, and s_{12} the cross spectrum then the squared coherency r_{12} is determined by

$$r_{12} = s_{12} * s_{12}^* / (s_1 * s_2) \quad (* \text{ denotes complex conjugate})$$

Deviations from the maximal value $r_{12}=1$ are caused by nonlinearities or additional noise sources. To eliminate interdependent correlations between different signal uptakes the partial coherencies are computed³. Therefore at distinct points which correspond with the uptake of the optical signals partial coherency values are obtained. These values are the basis of a map to be generated which refer to spatial analysis. This technique requires numerical solution of Laplace's equation which leads by well-known Taylor expansion to the solution of sparse systems of linear equations⁴.

Results

In Fig.2 coherency and partial coherency between two points are depicted in the range between 10 and 95 Hz. There is a dip proved in the values of the partial coherency in the range from about 23 to 37 Hz which indicates the occurrence of an additional source. Such a source was demonstrated by means of histology as an area of malignant cells (cutaneous metastasis of mamma carcinoma). In fact this result demonstrates the principal validity of the method. The uptake points were arranged in the same manner as in Fig.1. For further demonstration a map was constructed (Fig.3 a and b) by use of 8 signal points which therefore determines the spatial resolution. We add two figures in two different frequency bands, from 23 to 37 Hz, as indicated above, and from 37 to 95 Hz, where in power spectrum analysis the signals approximate the noise level of the analysing system. It is documented that in the first frequency band the boundaries of a malignant cells conglomeration are verified and may be distinguished from the surrounding tissue (again histologically proven). Darker spots mark lower partial coherency values. In the neighbored frequency band the boundaries will be blurred.

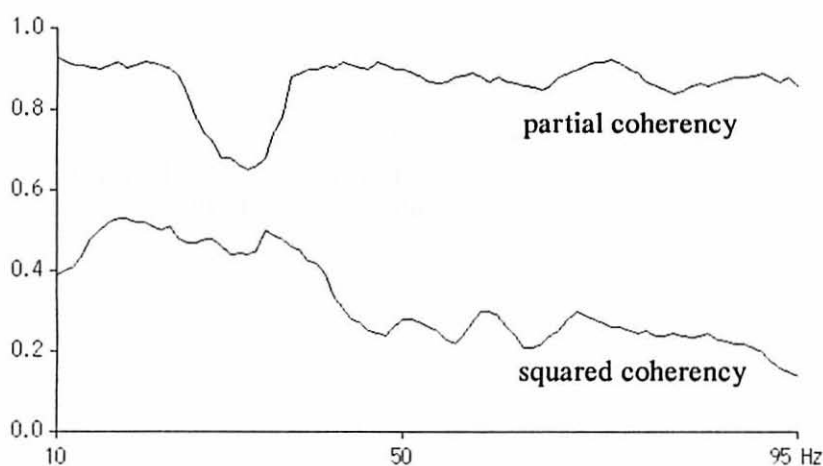


Fig. 2

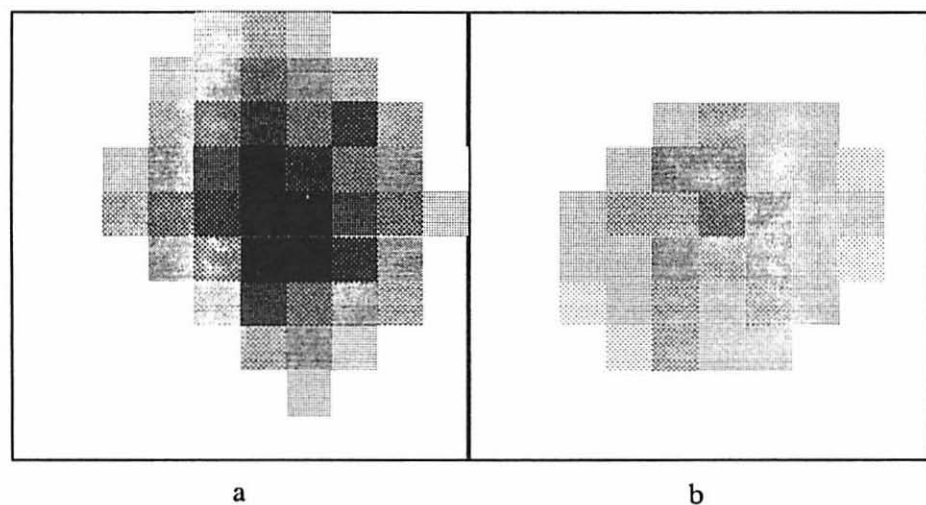


Fig. 3 mapping of partial coherencies, 8 outputs arranged in 2*2cm square

Conclusion

The described method seems to be valid for evaluation of fairly superficial located malignoma. Although the previous results seem to be encouraging we have to undergo further studies including different wavelengths of incoming light as well as noise modulation of different tumors.

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The Evaluation of a Micro-Computer Based Drill and Practice Tutorial as a Registry Review Modality for Nuclear Medicine Technology Students

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ABSTRACT

The purpose of this project was to evaluate the efficacy of a micro-computer based nuclear medicine physics drill and practice tutorial as an aid to nuclear medicine technology (NMT) students preparing for national certification examinations.

If a CBI tutorial is to be effective, then the post-tutorial responses from novices in the field should be equivalent to the responses from experts in the field for similar test instruments. Additionally, if a CBI tutorial is to be valid, then student responses on test instruments should indicate a positive effect over repeated measures.

A quasi-experimental nonequivalent control group design enabled the analysis to be based on multivariate analysis of variance of pretest and most test measures to make comparisons a) between nonrandom, nonequivalent groups, and b) within the treatment group. The CBI sample group (the novice group) was limited to one intact class of NMT students (N=8). The expert, or control group (N=9) consisted of certified technologists (CNMT) employed by local hospitals.

Multivariate comparisons of the CBI student sample and the CNMT control group pretest means resulted in a significant difference in the mean test scores at the 0.05 level. Comparisons of the student sample and the control group posttest means following the CBI treatment resulted in no significant difference in the mean test scores. This indicates that the CBI tutorial had some benefit in increasing the student performance when compared to the employed certified nuclear medicine technologists. Effect size ($ES=0.51$) for the posttest comparison was found to be of medium effect.

To support this CBI benefit finding, paired comparison T-tests were conducted on the CBI generated differential scores within the CBI treatment group. The T value of 6.62 for performance times and 3.80 for performance scores were significant at the 0.01 level, indicating positive CBI effect on the student group.

Comparisons of gender pretest performance measures were significantly different at the 0.01 level. Comparisons of gender performance measures following the CBI tutorial were not significantly different when mathematics aptitude or physics ability were considered as covariates. This suggests that CBI utilization has a positive effect on reducing gender performance differences.

KEYWORDS: computer based instruction (CBI)
nuclear medicine technology (NMT)
nonequivalent control group design
novice responses
expert responses
gender performance

^{99m}Tc-Labelled Nanocolloids in the Diagnosis of Postoperative Infections

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Introduction

The sequence scintigraphy with ^{99m}Tc-labeled nanocolloids is a helpful method in detecting acute and chronic septic osteomyelitis and early and late septical loosening of total hip arthroplasty (THA). In early postoperative and posttraumatic cases as well as after highly traumatic operations of the knee joint the differentiation between infection and aseptic inflammation was not possible. The aim of our study was to determine the potential of this method in differentiation of postoperative and posttraumatic changes vs. osteomyelitis and compare the scintigraphic findings and patterns of the scintigraphy with ^{99m}Tc-labeled nanocolloids and ¹²³I-labeled anti-granulocyte MAB.

MATERIALS AND METHODS

55 patients after bone trauma or surgery as well as 20 patients after total knee arthroplasty (TKA) with a mean age of 57 yrs. (7 to 85) were investigated with 3 phase ^{99m}Tc-Nanocoll-scintigraphy, in equivocal cases (n = 25) additional I-123-NCA-MAB-Scintigraphy were performed.

After bolus injection of 370-740 MBq ^{99m}Tcm-labeled nanocolloids (Nanocoll^R, Solco Basle Ltd.) acquisition of analog and digital sequences were done, "pathological" enrichment was additionally correlated to anti-granulocytes-antibody-uptake. The perfusion index was calculated with semiquantitative ROI-technique using commercial software (NPS-Philips).

The scintigraphic results were correlated with the clinical, laboratorial and radiological findings.

Results

The diagnostic problem were positive findings as normal pattern in distinct aseptic inflammation after highly traumatic knee operations such as osteotomy. In these cases a differentiation between infection and aseptic inflammation was not possible. Nanocoll-scans was not much helpful, because of the unspecific Nanocoll enrichment in early postoperativ and posttraumatic alterations without clinical signs of infection. In some cases of severe bone fractures and non unions slightly positive findings as an expression of the unspecific inflammation were found, and leaded in some cases to false positive diagnosis of infection. Nanocoll-scans showed in nearly all cases diffuse uptake also in the surrounding tissue of the bone leading to a (false) positive result.

Conclusions

Scintigraphy with nanocolloids is proven a useful method with high sensitivity (93,8 %) and specificity (96,4%) for diagnosis and therapeutic management in osteomyelitis and in the early and late phase after hip arthroplasty. Due to the constant availability, easy applicability and low cost, the method is recommended as clinical routine in the diagnosis of late infections (more than 6 months after operation) in bone and joint surgery. It is seen as less effective, however, in the diagnosis of early infections after extensive knee operations and surgery of peripheral joints and bones where in most cases the differentiation to aseptic inflammation was not possible.

In this cases granulocyte scintigrams were useful for better delimitation of the infection process with probably higher specificity.

Improvements in Volumetric Imaging by Means of Spiral-CT

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The introduction of Spiral-CT [1,2] has fueled renewed enthusiasm for Computed Tomography. The technique was provided by CT-scanners like the Somatom Plus, which utilizes fast and continuous rotation of the whole measurement system in combination with the continuous movement of the patient table during data acquisition. Therefore the focus describes a spiraling path relative to the patient (see figure 1). Spiral-CT enables the coverage of whole organs in shortest time possible, while minimizing respiratory misregistration and motion artifacts. Because the data of the entire scanned volume is available, it becomes possible to reconstruct images at any arbitrary position within the volume resulting with more or less overlapping stacks of CT-images.

Because of these features, Spiral-CT images are expected to be advantageous for volumetric imaging like multiplanar reconstructions (MPR) and 3D techniques. We compared the quality of volumetric images of an anthropomorphic phantom of a hip obtained by conventional dynamic scanning with the results of different spiral protocols. In each of the studies, the same anatomical area was scanned with identical parameters for measurement and image reconstruction. The conventional study was performed with 5mm collimation and 5mm table-feed (5mm/5mm). Spiral data were acquired also with 5mm collimation and a table-speed of 5mm/second. Axial images were reconstructed from the same spiral data set to form either 'dense' (2mm increment) or 'loose' (5mm increment) image-stacks. For the rendering of 3D-surface images, regular scanner software was utilized, based on a derivative of the gray-value gradient shading method [3].

The resulting frontal 3D-images are shown for the conventional scanning in figure 2, and for the Spiral in figure 3 ('loose') and in figure 4 ('dense'). For qualitative rating we used the degree of the stepping artifact, caused mostly by partial volume effects. This artifact is most pronounced when scanning conventionally (fig 2).

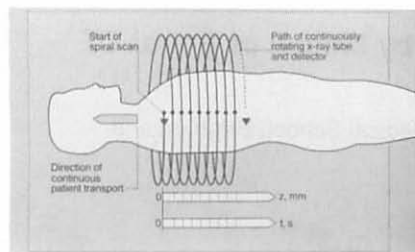


Figure 1: Scanning geometry at Spiral-CT

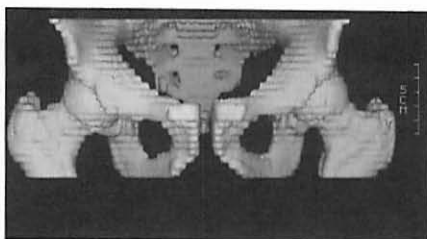


Figure 2: 3D Rendering of a conventional data-set 5mm/5mm

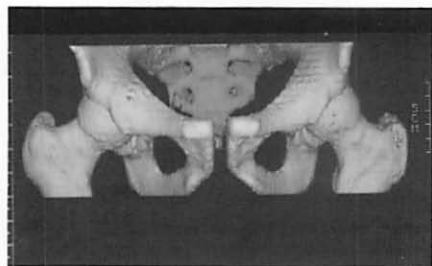


Figure 3: 3D Rendering of a Spiral-CT 5mm/5mm reconstructed each 5mm

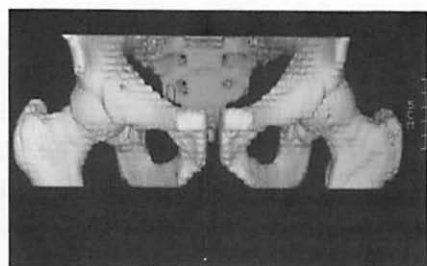


Figure 4: 3D-Rendering of a Spiral-CT 5mm/5mm reconstructed each 2mm

A slight improvement is seen in the loose Spiral case. In the recent implementation of Spiral-CT the sensitivity profile is enlarged due to the interpolation between measured projections to correct for the table movement. The effective slice-thickness here is about 6mm, resulting in an overlap (slice/table-feed) of 20% and accordingly less stepping. The image in figure 4 clearly reflects the advantage of a dense Spiral, especially when compared to conventional scanning. Here the volume was reconstructed with a slice-overlap of more than 200%. It is known from other studies [4] that a certain amount of slice-overlap improves the quality of 3D and MPR images. However, this requires more slices to be measured and more dose to the patient. When utilizing Spiral-CT, it is possible to reconstruct highly overlapping slices without increasing the patient dose. These advantages of Spiral-CT are expected to have clinical benefits.

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Accuracy in Three Dimensional Reconstruction of Coronary Vessel Systems from Biplane Angiographic Views

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In our poster a system for three dimensional reconstruction, modelling and visualization of coronary vessel systems from biplane projections is presented. The geometric reconstruction is applied to image pairs. It allows spatial views on a vessel system from different directions, as well as the exact localization of vessel points and their geometric relationships. Furthermore it is possible to determine the projection parameters for optimum imaging of a specific vessel segment, thus the patient's radiation exposure can be reduced. The geometric fundamentals of imaging and reconstruction are presented. Solutions for problems concerning the accuracy of the acquired imaging geometry and biplane correspondence have been developed. The presented work was verified with the help of both synthetical and real phantom images, and with examples from the clinical routine.

1. The 3-D Reconstruction Process

As shown in Fig. 1 the reconstruction process starts with acquiring imaging data. The biplane images are rectified to avoid any errors caused by geometric distortions of the imaging systems. To get precise results the relevant geometric parameters at imaging time have to be acquired as accurate as possible. The available device parameters (x-ray system orientations and distances, visible size of image intensifiers, etc.) are important attributes of the image pair. All coordinates are related to the isocenter, the common origin of the x-ray systems [1,2]. In both projections the user marks some significant nodes (e.g. vessel system origin or bifurcations) to define the topology of the vessel tree and the region of reconstruction. Along these nodes the vessel course and edges are determined automatically from the images [3]. In result the 2-D models for each projection consist of a number of vessels splitted into segments by the user given nodes.

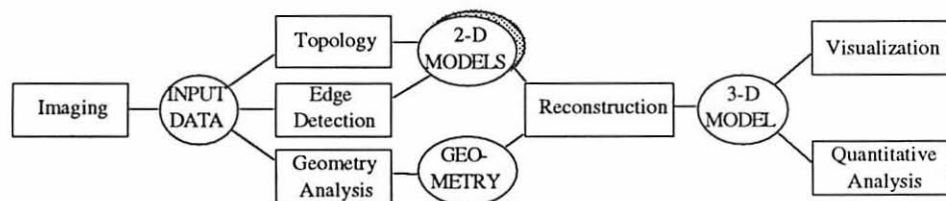


Fig. 1: Reconstruction Pipeline

During the imaging process an object point is pierced by one ray for each projection and decreases their intensities. The world coordinates of this object point may be recalculated by reconstructing the rays from the corresponding projections and the geometric parameters. Theoretically the reconstructed rays should intersect in the object point, in practice they will miss in most of all cases because of discretization or remaining errors in geometry parameters [4,5]. Those points on each ray are searched which are closest, and the weighted middle of them is taken to be the object point (Fig. 2). As a feedback within the reconstruction pipeline the user is supported in finding the corresponding points by reprojected rays of the other projection (auxiliary lines). The segment reconstruction is performed analogous to the node reconstruction, but the segment elements produce a ray bundle for each projection. Those elements are corresponding where the ray distance is minimum. An algorithm to find the optimum correspondence path has been developed and described in [2].

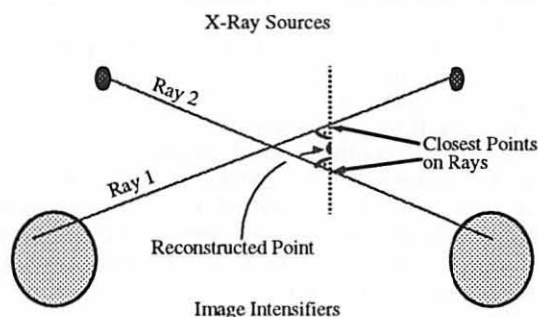


Fig. 2: Point Reconstruction

From the derived vessel edges the cross section is reconstructed. For each segment element in each projection a vessel radius is calculated which results in a pair of spatial radii for each reconstructed element. Because the amount of spatial information depends on the vessel orientation to the projection rays, a variable cross section modelling method has been developed. It varies from elliptic (rays orthogonal to vessel -> best case) to circular contours (rays parallel to vessel -> worst case).

2. Geometry Approximation

The main problem in reconstruction accuracy is the acquisition of the geometric parameters. While the viewing angles can be easily determined by using a scale mounted on the imaging device, the required distances from each x-ray source and image intensifier to the isocenter are heavily determinable. Manual measurement is unsuitable for finding the isocenter location. Phantoms can be imaged to determine the distance portions for a given imaging geometry. This method is precise but rarely applicable in practice. Biplane calibration methods using a known distance in the original x-ray images (e.g. two markers on the catheter) are more practicable.

To derive the imaging geometry from a user chosen set of corresponding points and the known device parameters the following new approach has been developed: Beginning with an initial geometry derived from the imaging parameters the geometry is approximated. A dimension for geometric correlation is given by the errors resulting after reconstructing the corresponding points. These reconstruction errors can be used

to determine the correction coefficients for a better approximation. If calibration and viewing angles are correct, three different error types have to be distinguished:

- a) shifts of the x-ray systems orthogonal to both projection axes
- b) magnification errors caused by wrong distances in relation to the isocenter
- c) perspective errors caused by a wrong source - image intensifier distance

In Fig. 3 the effects of these errors are shown. Error type a) results in a constant error independent from point location. Errors of type b) depend on the distance of a projection ray to the projection axis, and is undetectable if the point is near the axis. Type c) depends on both distances to the projection axis and the isocenter level. For objects near the isocenter level an error portion cannot be determined.

■ Projection of an object point

— corresponding ray of the other projection

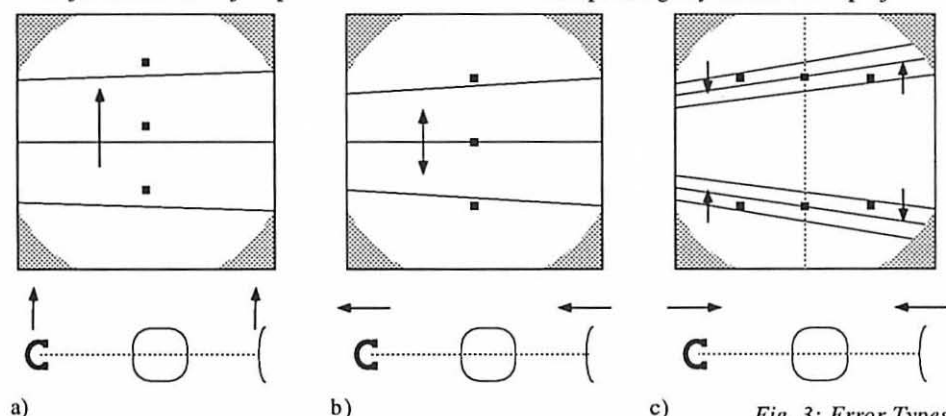


Fig. 3: Error Types

The errors are independent from each other, but the correction of one error results in a different assumed geometry and in new conditions for recalculating the correction coefficients. Because of this fact linear methods which try to correct one error after another do not work sufficiently. New iterative methods to extract correction coefficients for all error sources in one step have been developed and implemented. Regressive methods are often used for error extraction from a given set of reference data. In our case the three error coefficients b_a , b_b , b_c have to be determined from a total error $y = b_a z_a + b_b z_b + b_c z_c$, where z_a , z_b , z_c are functions of the location of an object point (e.g. $z_a = 1$ because error a) is position independent). They can directly be used to correct the assumed geometry. Because the regression process gets unstable on low point location variances, coefficients are discarded when the conditions may cause implausible values, and a lower level regression is performed.

Alternative to the regressive method a new mean value based algorithm has been developed. For each error vector its portion of one error type is extracted. The weighted mean value is used to determine the correction coefficient. Afterwards the mean error portion is subtracted from each point error, and the reduced errors are used to determine the portion of the next error type. This method guarantees a deterministic behaviour even in those cases where the regressive method creates inconsistent results. Because each point and each error type owns a specific weighting factor, there is no hard switch

between considering an error type or not.

After the determination and correction of the global error, remaining local errors have to be considered during the reconstruction process. To look for the optimum segment correspondence path, and for reconstruction of the segment elements, the error vectors of the surrounding nodes are interpolated along the error direction. These local errors are subtracted from the determined element errors, thus the assignment of corresponding segment elements is correct according to the surrounding nodes.

3. Results

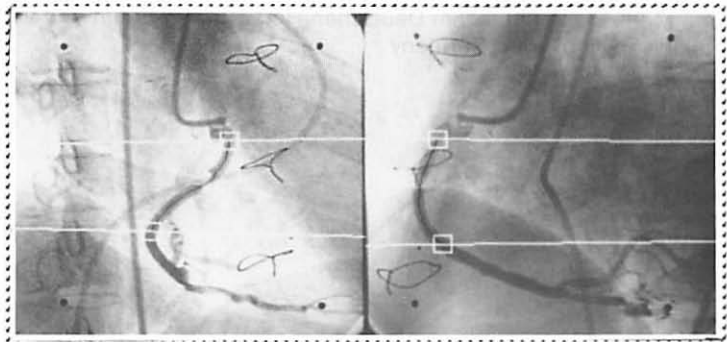
At first, synthetically generated images were used for geometry determination and reconstruction. Projections of a synthetic cube with 40mm edge length have been evaluated. For reconstruction the isocenter distances have been changed up to 70mm to simulate the geometry error. The mean reconstruction errors were approx. 2mm. After applying the error correction algorithm the distances of the assumed and the original geometry differed up to 0.012mm. The reconstructed corners matched the original coordinates with differences less than 0.001mm. For the evaluation of real images a spiral phantom of 192mm in length and 30mm in diameter has been imaged. The calibration was performed using a cubic phantom. The measurement error after reconstruction were 1.1mm in length and 0.3mm in diameter.

The images can be acquired either by digitizing angiographic cine films or by digital data transfer from the x-ray device (e.g. Philips Digital Cardiac Imaging). In Fig. 4 a clinical application is shown. The interactive marking process is shown as well as the reconstruction results. For a first visual impression a wire frame representation is used. A triangulation algorithm has been developed for a special graphics hardware to get realistic images. The contours are triangulated to calculate a surface model. The resulting 3-D model is displayed using Gouraud shading [6].

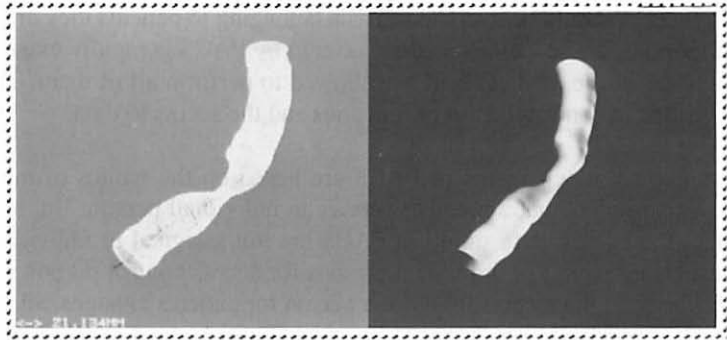
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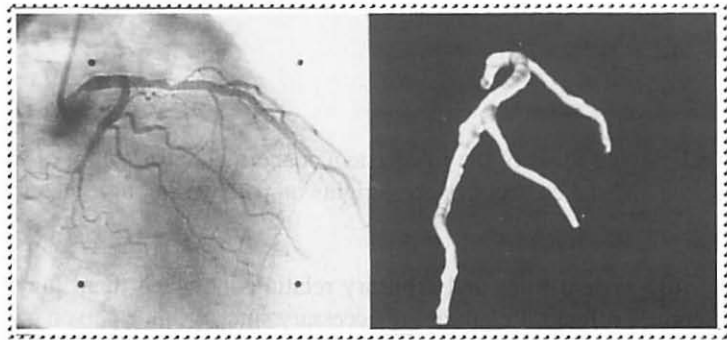


X-ray Images of a Stenosed Right Coronary Artery with Markers and Rays



Reconstructed Wire Frame Model

Triangulated and Shaded



A more Complex Vessel System
of a Left Coronary Artery

Shaded View (Rotated)

Fig. 4: Results

The Significance of a Role System for the Security of PACS

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1. Introduction

More and more image data acquired within medical institutions are stored in PACS. All members of the medical staff have access to the PACS. Due to confidentiality and privacy this access should be restricted to data belonging to patients they are concerned with. Furthermore, the scope of functions offered by PACS is rapidly expanding. And not all members of the medical staff are allowed to perform all of them. Therefore, a system is needed to control the use of functions and the access to data.

The access control mechanisms of PACS are based on the names of medical staff members. This implies that a member acts as an individual person. But in a medical environment the patient data stored in PACS are not assigned to individual persons but to roles. Using names of individual persons for access control purposes result in a further drawback. If the responsibility of a person for patients changes, all patient data the person is authorized to access has to be updated with respect to access rights. If the access right control is based on roles only the assignment of a person to a role has to be modified. For that reason a role system is needed that takes these aspects into account.

2. Role system

The two underlying ideas of the role system concern the abstraction of users to their functional role and the control of access rights on patient data in terms of functions a role may perform.

Within the role system roles and arbitrary relations between them may be defined using the services offered. Relations are necessary since a single person can play more than one role at a time. Each role is assigned to a set of persons that may play this role and a set of operations specifying a document and a set function the role is allowed to perform. The *documents* of the role system comprise the image information archived in PACS and the *functions* reflect the operations offered by PACS. Two kinds of relations are distinguished. The *is_a*-relation permits modelling

multi-hierarchy structures where a subordinated role inherits the access rights of all its superior roles. Opposed to this the *hierarchy*-relation supports modelling of hierarchy structures where a role doesn't inherit the access rights of its superiors. The role system follows a domain concept. This means several autonomous role systems residing at different locations handling local access to PACS may interact to support remote access. For this purpose the concept of *remote_roles* has been introduced. By this a remote structure or substructure can be linked as a substructure into the local structure. The following formal description reflects the model the role system is based on:

```

role_model ::= sequence of {
    set of roles,
    set of relations,
    set of services }

relations ::= sequence of {
    set of is_a_relations,
    set of hierarchy_relations }

roles ::= choice of {
    local_roles,
    remote_roles }

local_roles ::= sequence of {
    set of persons,
    set of operations }

operations ::= sequence of {
    document,
    set of functions }

```

Since different users with the same access rights may be grouped by roles these rights have to be only managed one time. Furthermore if the rights of a single user change s/he will simply be assigned to another role. This decreases the managing effort with respect to updating the access rights.

Each role can exactly be assigned with the necessary rights taken several levels of abstraction into account. By this the managing overhead is reduced since the Access Control Matrix can be kept small as there are fewer roles than users and less access control information is assigned to images.

3. Conclusion

For the provision of appropriate access control methods to PACS it is necessary that as low as possible administration effort is needed. For this purpose an abstraction of users to their functional roles is helpful. Therefore a definition of roles and relations between them must be supported by an access control method. Since a PACS is a distributed system and the role system also follows a distributed approach it fits well into the concept of PACS.

A Method for Fast Segmentation of 3D Connected Objects*

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1. INTRODUCTION

The purpose of this work is to present a new method for segmenting connected objects by using volume data. The method aims to reduce processing time for general-purpose computer architectures and to minimize the user's interaction.

Two basic alternative approaches are usually adopted for segmentation of 3D objects. One consists in a direct processing of voxel data, the other utilizes the reconstruction of the object's surface obtained via the extraction of the 2D object's contour by a slice-by-slice procedure. The major difference lies in the fact that the latter approach postpones the use of 3D information until the end of the whole 2D processing, while the former makes use and processes 3D information from the very beginning of processing.

The method has already been extended to some 3D numerical processes (e.g. edge detectors [1,2] and region- growing algorithms [3]). However, such methods are generally unable to segment an entire object correctly; in addition, they are very time-consuming and require special-purpose hardware.

The present method involves a closer interaction and a feedback mechanism between 2D and 3D information, as segmentation of a slice can benefit from information provided by neighbouring slices as well as from 3D object reconstruction. For 3D segmentation, we exploit fast 2D processing algorithms, but do not accomplish the specific and time-consuming task of extending them to 3D space.

The major innovative aspect of the proposed approach consists in performing several 2D processing steps to obtain 3D segmentation results. During such 2D processing steps, the 3D information is also utilized, thus achieving an integration of planar and volumetric data, just from the beginning of processing.

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The method consists of two main phases, namely, the "2D contour following" and the "pseudo-3D processing".

In the first phase information is propagated between the slices of a spatial sequence to facilitate the detection of an object's contour. This is the starting point towards the use of some preliminary information about the correlations between the various planes. Such information is acquired by projecting some processing results from a plane on the neighbouring planes.

In the second phase, a more direct use is made of 3D information, that is, the correlations among the object's 2D extracted contours belonging to the various planes are used for a pseudo-3D processing.

The two phases are first executed in a sequential way. The second phase can be applied only if the first phase produced segmentation results for the original planes, and aims to rectify possible errors. The sequence of the two phases is usually repeated, thus implementing a feedback mechanism.

The first phase is performed by using an iterative procedure that alternates local and global analyses, and that yields better results if several steps are executed.

Evaluations of results and time performances drive the choice of the number of iteration steps required. Obviously, reducing the iterations in the first phase produces the need for more feedback between the two phases, that is, more errors may be detected that must be rectified in the second phase.

The paper presents detailed descriptions of the two phases, which involve the use of algorithms based on some classical methodologies, such as "the Chamfer distance" [4], and "snakes" [5].

The method was applied to tomographic images, assuming a slice of the image sequence to have been correctly segmented.

Results will be presented and discussed.

2. PROPAGATING 2D INFORMATION BETWEEN SLICES

Some information can be transferred from a slice to the next by projecting the contour of an already segmented object. This allows one to approximately predict the shape of the contour's location in the new slice. Then, some iteration cycles are executed, consisting in local searches for good contour sharp, and in a global elastic deformation.

For this local contour analysis, the method of the chamfer distance [4] can be used as to take into account translational and geometric deformations undergone by

the contour from one slice to another. The edges extracted from the current slice are now compared with the contour in the previous slice. To speed up the process and to impose the constraint of continuity on the object boundary, contour primitives are selected as patterns for the matching procedure, instead of edgel primitives, which are generally utilized in elastic matching.

In the present system, the Canny [6] method is adopted for the edge-detection step. After edge extraction a first edge selection is made using the Chamfer distance; all the edges whose distance from the reference contour is greater than a fixed threshold are not considered in the successive processing. At this point we use a radial methodology to analyze all the edges and to select the edges with the best features. Some particular features of the contour primitives are also considered, such as the gradient strength value and a new parameter, i.e., "*persistence*", by which one can measure how close to the reference element the edge lies. *Persistence* is an original cost function that can be defined as:

$$length * strength^2 / variance \quad (1)$$

and that takes into account the length and the strength of an edge. Variance is a very interesting parameters, as it describes the morphological evolution of the edge with respect to the reference contour. It is defined as:

$$variance = \frac{1}{length} \sum (d_i - \bar{d})^2 \quad (2)$$

where d_i is the distance of pixel i from the reference contour and $\bar{d}$ is the average distance of the edge.

At the end of this phase, we perform a selective closing of the remaining edges to eliminate possible errors made in the selection based on *persistence*. Such a closing is driven by morphological information derived from the starting reference contour.

The method of snakes is applied in a subsequent phase to impose the constraint of contour continuity. At this time the contour parts have been already selected and some parts have been eventually added to produce a closed boundary.

The method of snakes applied takes into account the boundary continuity and image gradient parameter. The main goal is to minimize a cost function given by:

$$E_{snake} = \int_0^1 E_{intr}(v(s)) + E_{image}(v(s)) + E_{con}(v(s)) ds \quad (3)$$

where the above two parameters are such that input boundary is forced to pass through the highest gradient and must have a continuous evolution. We have evaluated some parameters by several tests. One determines the contour smoothness: larger values correspond to a low shape frequency; larger values of the other parameter

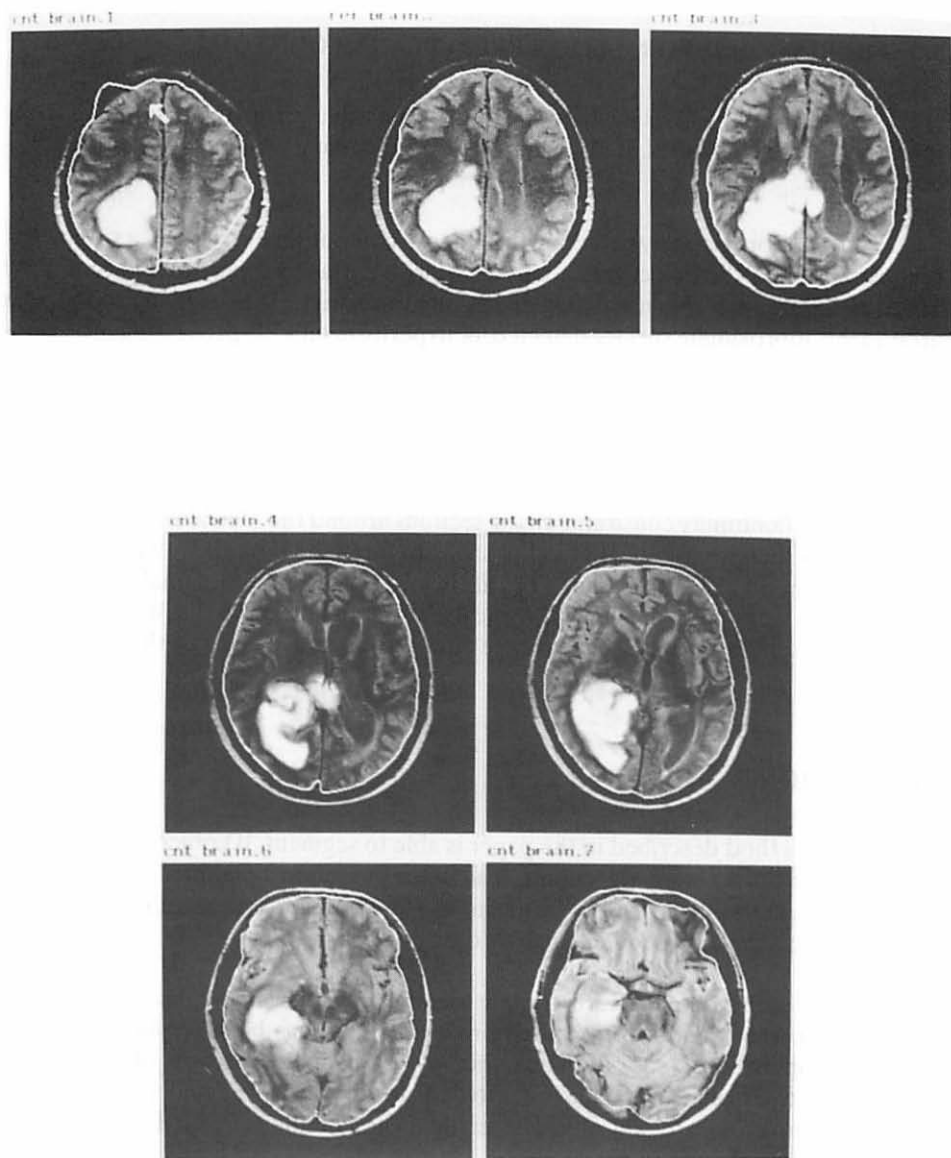


Figure 1: Results obtained on a sequence of 7 brain images before pseudo-3D correction; a) levels 1,2,3 b) levels 4,5,6,7

pushes the contour on the image gradient. It should be stressed that the method of snake is very noise-sensitive, so care must be exercised necessary in setting the value of these parameters. Application of this phase to a real sequence of medical images is displayed in Fig.1a and 1b **.

3. INFERRING 3D INFORMATION FROM PLANAR CONTOURS

The second phase is devoted to detecting possible errors that cannot be easily found on the single planes. It also supports 2D processing when various alternatives are available.

After approximately detecting the object's contour on every slice, a volumetric reconstruction of the object is generated to derive surface properties and to impose 3D constraints. Such reconstruction allows one to restrict 3D processing to the area around the approximate surface detected, or to perform only 2D processing on various sagittal planes.

An error is supposed to be pointed out by a discontinuity in the surface of the object volume. In particular we use an algorithm proposed by Pavlidis[7] to detected such discontinuities and we rectify this kind of errors using both 3D and 2D information. We impose a continuity constraint on the sections around the one where we detected an error and then we use the method of snake to force the boundary to pass through the gradient points. This procedure does not involve a high computational cost because we choose to work on a sequence of vertical planes rather than in the 3D space. Fig.2 shows the result on the medical sequence after the correction, due to the pseudo-3D processing.

CONCLUSIONS

The method described in the paper is able to segment 3D objects correctly by using only 2D processing algorithms. The 3D information contained in the spatial image sequence is fully exploited by means of a preliminary propagation of contours between slices and a subsequent analysis of sagittal planes.

The results obtained are a quite significant achievement, as contours are sufficiently correct, and a very limited processing time has been required. In some practical applications (e.g., radiation therapy) a manual detection of an object's contour on each plane can thus be avoided. Moreover, a manual correction for segmentation errors are still much faster than the complete manual segmentation usually performed.

** Images were acquired with a Philips GYROSCAN T5 (0.5 Tesla) MR Tomograph

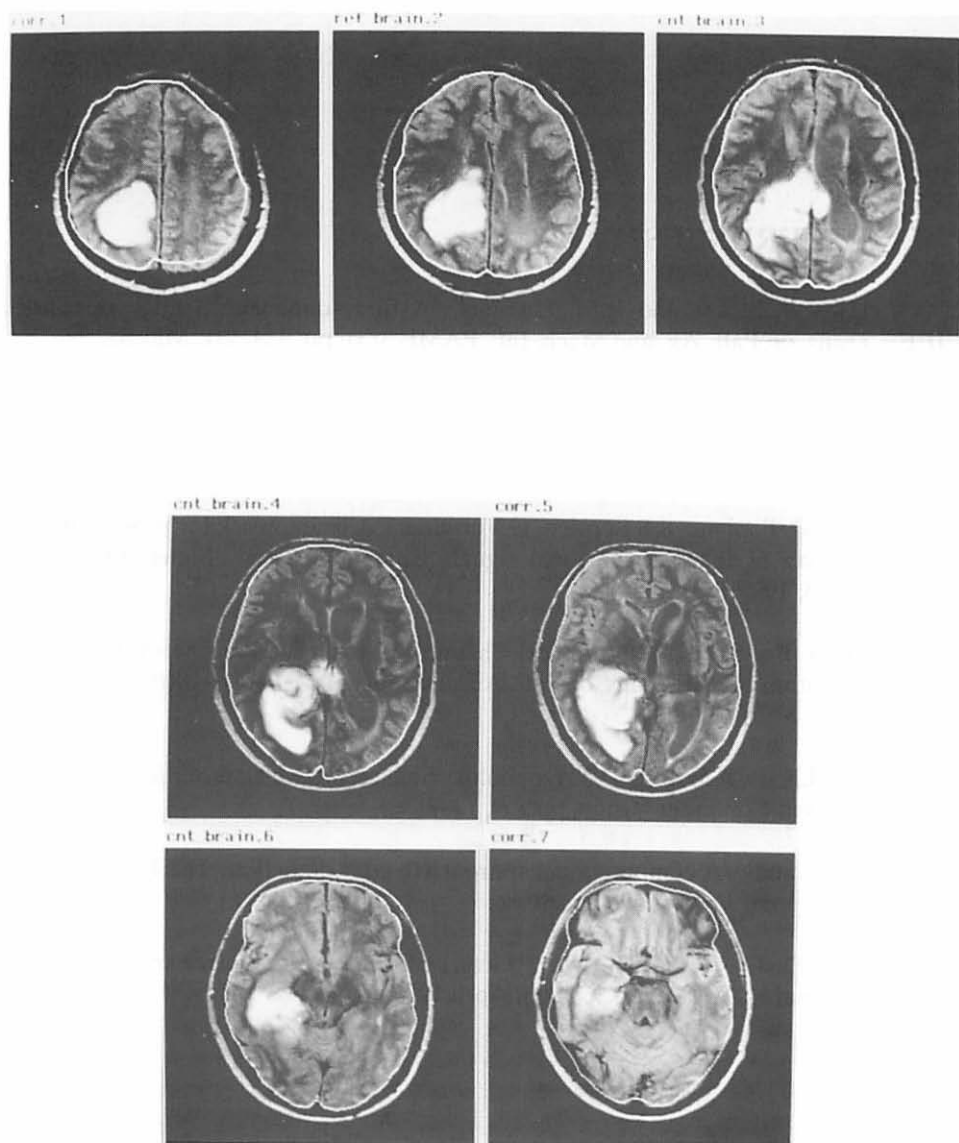


Figure 2: Results obtained after the pseudo-3D correction (improvement on level 1,5,7); a) levels 1,2,3 b) levels 4,5,6,7

The method has been implemented so as to segment only one object at a time. Its extension to cope with the problem of segmenting several objects at the same time will be allowed in the future.

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A New Approach to Digital Filtering

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I. INTRODUCTION

Digital filtering is an important technique in all areas of medical imaging. The theoretical basis is the same regardless of the choice of imaging modality: computer-assisted tomography (CT), magnetic resonance imaging (MRI), nuclear medicine scanning (ECT, SPECT), or computer analysis of radiographs (1-3). A number of approaches have been taken, most of which involve the use of Fourier transforms and one of a number of conventional filters, such as the Legendre or Optimal filter, the Chebyshev filter, and the Butterworth filter (4). In the work described here, a new set of digital filters based on the class of Cohen orthogonal functions is described. Using this general class of orthogonal functions, both three-pole and five-pole filters can be derived, which can be used to produce low pass, high pass, and band pass filters (5-7).

II. FILTER DESIGN

The new class of digital filters is obtained from the family of Cohen functions given by the equation:

$$F_n(m, a_t; s) = \sum_{k=0}^n \frac{\prod_{i=0}^{n-1} (m + a_i + a_k)^{a_k}}{\prod_{j=0}^{k-1} (a_j - a_k) \prod_{s=1}^{n-k} (a_k + s - a_k)} \quad (1)$$

where

$$\prod_{j=0}^{k-1} (a_j - a_k) = (a_0 - a_k)(a_1 - a_k) \dots (a_{k-1} - a_k) \quad k \geq 1$$

$$\prod_{s=1}^{n-k} (a_k + s - a_k) = (a_{k+1} - a_k)(a_{k+2} - a_k) \dots (a_n - a_k) \quad n \geq k$$

A polynomial subclass of the Cohen orthogonal function is used. Poles are then obtained using the Newton-Raphson iteration method, which are in turn used to

define the transfer functions, which result in a number of three and five pole filters. From these, low pass, high pass, and band pass filters can be designed.

III. RESULTS

The above filtering techniques have been incorporated into a comprehensive system for imaging research (8). The system is implemented on a SUN SPARCstation 470 computer. Radiological images are digitized using an AT&T Targa Image Processing Board on an IBM PC and then transferred to the SUN. All routines are written in C. The image processing system consists of the following components: View (displays stored images); Live (digitizes new images through a video camera or other digitized media); Enhance (includes the following: mapping, smoothing, histogram equalization, histogram stretching, grey level stretching with thresholds, edge sharpening, change of number of grey levels, scaling, and conversion to black/white); Filter (includes the filters described above as well as conventional filters); Geometry (includes zooming and copying); Measure (determines the actual size of an area of interest); Arithmetic (performs AND, OR, and XOR).

Analysis of the behavior of this set of filters indicates a number of interesting properties. First, the Legendre, or optimal filter, is a special case of this general class. Secondly, comparison of the transfer functions of these filters by means of frequency versus amplitude plots indicate that they fill a gap between the Butterworth and Chebychev filters.

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Integrating PACS With Radiology Reporting

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The end product of the radiology department is the radiology report. Its purpose is to promptly provide the referring physician with diagnostic information most useful for clinical decision making. The importance of this function demands that the full power of advanced technology be relevantly applied to enhance its value to the clinician.

The radiology report typically consists of the transcribed text of a radiologist's verbal interpretation. To shorten delays, phone access to a digital dictation system provides the option for immediate reporting. However, a picture is worth a thousand words. And yet the medical image is available only to clinicians who make a special effort.

Since the PACS era finally seems to be upon us - albeit in embryonic form - we must rethink the process, form, and content of the radiology report. As soon as the dictation is completed, an integrated report consisting of both the dictation and selected images should be instantly available to the referring physician. For urgent reports, the physician can be automatically notified by phone or pager. The final typed report should also incorporate at least one relevant picture (image).

To provide this capability, a radiology department must install a digital dictation system, a radiology information system, and a PACS - all fully integrated or interfaced. DDSs and RISs are mature and cost justifiable; department-wide PACS is neither mature nor cost justifiable. However, PACS for nuclear medicine, and perhaps CT and MRI, can be justified today.

The core of such a system is a network with the ability to acquire, store, retrieve, translate, communicate, and display multimodality medical images from any manufacturer's equipment. This same network must link to the digital dictation system, RIS, and HIS. All the relevant functions of the radiologist would then center around an image display and reporting workstation. A single PC would provide for instant image retrieval, image analysis, dictation with automatic patient identification, optional speech recognition and structured reporting, retrieval of prior reports/images from any modality, electronic signing of transcribed reports, access to pathology reports and other clinical information on the HIS, etc.

This is the future of radiology. The seduction of technology, however, is tempered by the current limitations and costs inherent in handling those studies that require many megabytes of data to be stored, communicated, and displayed. But let's not wait any longer to experience the power of the integrated radiology workstation. We should take that first, cautious, yet exciting step into PACS/reporting for nuclear medicine, CT, and MRI....and pave the way into the future of multimedia radiology reporting.

Patient Defined Digital Angiocardiology (PDDA): A Valid Way for Individual Staging of Coronary Artery Disease

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I. INTRODUCTION

During the past decade most studies from various institutions have used visual interpretation of coronary angiograms as the reference standard for determining the presence or absence of significant coronary artery disease. This method is plagued by a high level of interobserver and intraobserver variability. The development of quantitative coronary angiography has eliminated most of the difficulties associated with visual interpretation. The reproducibility of repeat quantitative measurements is excellent, but the reliance on the reproducibility of repeat coronary angiograms is limited. Progression and regression of coronary atherosclerosis are judged according to changes in the measurements of stenoses obtained from a coronary angiogram. A major limitation of serial angiographic studies is that repeat angiograms are subject to variations in all parameters such as image angulation, magnification and contrast density leading to poor agreement of relevant images for quantitative analysis of follow-up studies. Therefore the reproducibility of repeat coronary angiograms is primarily dependent on the precision of the procedure and only secondary related to the reproducibility of repeat quantitative measurements.

Today's and future interventional cardiology demands a valid concept for the quantitative assessment of progression and regression of coronary atherosclerosis with optimal precision and reproducibility. Computerized quantitative assessment is the only acceptable method to study the efficacy of such interventions, but even this technique has inherent limitations and difficulties related to the interpretation of the angiographic information. These problems may be solved by a new patient-defined, standardized and reproducible form of digital angiocardiology as a fundamental prerequisite to realize a fully digital catheterization laboratory.

II. PDDA - SYSTEM

This Patient Defined Digital Angiocardiology (PDDA) - Configuration consists of a biplane image acquisition system with a 23cm HDR image intensifier with 1,024 x 1,024 x 10-bit matrix, a storage system with RAM solid-state memory for 16/14 seconds scene length (50/60 Hz) including 4000 image storage capacity, a 32-bit CPU with high-performance image processor for high-resolution real-time processing, a post-processing work station (SUN SPARC2) and a digital archive (Fig. 1) A

cine projector with TV-chain for digitizing of 35mm films (ARRIPRO 35) and standardized VHS/S-VHS (CCIR-Standard) and hard copy outputs are also available.

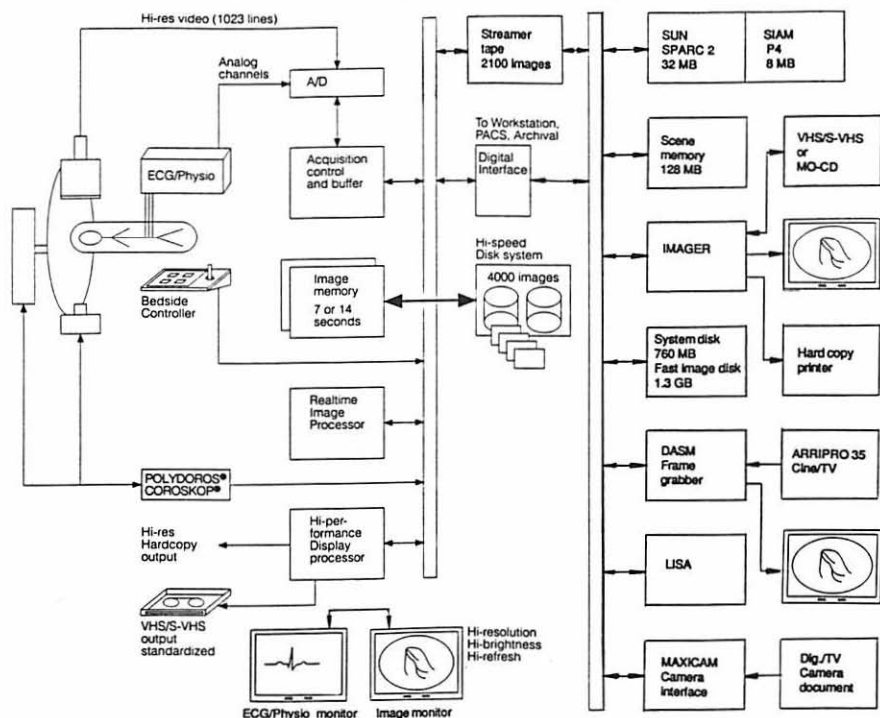


Fig. 1. PDDA Block-Diagram

At the initial diagnostic angiocardiology of a given patient, optimal projections according to individual anatomy are selected and stored as technical and radiological parameters together with representative reference images on high resolution S-VHS video tapes and/or on a magneto-optical medium for each patient. The individual acquisition of patient-defined technical parameters assure the automated adjustment of the biplane angiographic imaging unit at any follow-up angiocardiology. The sequences of a repeat angiogram are being automatically compared to corresponding images of the individual patient-defined reference. Various standard methods for quantitative coronary angiography and ventriculography can be applied during post-processing.

III. CONCLUSION

PDDA represents a configuration for high definition digital angiocardiology with digital archiving of both images and technical data to assure an optimal individual reproducibility. Thus, with the automated adjustment to the primary individual patient-defined reference, follow-up assessment of coronary morphology allows for true quantification of natural progression of coronary artery disease or regression resulting from pharmacologic or mechanical therapeutic interventions. PDDA is a configuration of a digital angiographic system to realize the fully digital catheterization laboratory today with all options for future developments.

Dosimetry for Boron Neutron Capture Therapy Research

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A collaborative program under the direction of the Idaho National Engineering Laboratory has been ongoing since 1988 to develop boron neutron capture therapy (BNCT) for eventual treatment of human brain cancer. A subtask of this program involves injection of ^{10}B -enriched borocaptate-sodium (BSH) into dogs (50 mg B per kg) which are exposed to a reactor neutron beam which is filtered to transmit primarily epithermal neutrons. The epithermal neutrons are thermalized by the head tissues, and captured by the boron which has entered the tumor via its blood supply. Cancer cell damage is from the heavy fragments from the $^{10}\text{B}(n,\alpha)$ reaction. The treatment planning model is based on Monte Carlo calculations (for each dog) of interior neutron flux and gamma doses using the measured incident neutron spectrum, and measured blood B concentration. It includes the effects of boron capture, reactor and hydrogen capture gamma rays, and the $\text{N}(n,p)$ reaction. Dosimetry for model verification of this indirect method of treatment is based on measurement of external neutron flux using neutron activation of gold/copper samples, and direct measurement of external gamma exposure using thermoluminescent dosimeters (TLD) Calcium Fluoride Manganese ($\text{CaF}_2\text{.Mn}$) chips at various head and body locations. This dosimetry has been benchmarked against internal gamma and thermal neutron measurements in phantoms. To date, irradiations have been administered to plastic head phantoms, and (under veterinary direction) to 36 healthy dogs to determine dose tolerance and 20 dogs having spontaneous brain tumors.

Preparation of the thermoluminescence dosimeters, their processing using a modified Harshaw Plachet reader and the calculation methods using inhouse-developed computer programs will be discussed. This method can be used in diagnostic radiology, nuclear medicine, and radiotherapy to estimate the radiation dose delivered to the patient.

Tests of the AGFA Phosphor Plate Imaging System in Pediatrics

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Digital radiography using the Agfa phosphor plate imaging system is undergoing clinical testing at the Georgetown University Department of Radiology. This exhibit will demonstrate the results of our tests.

The digital imaging system provides advantages in

1. Semiautomatic masking of the image resulting in images that have a gray background in the region outside the collimator limits, thus decreasing glare. Because the collimated image of a neonate is smaller than the film size used for the radiograph, the clinical image is usually surrounded by clear film resulting in a large amount of light reaching the eye of the radiologist. The Agfa ADC currently provides a method of semi-automatic collimation of the image providing a gray mask around the image. In the future, the company plans to make such masking to the collimator edges automatic. With the current system, the light reaching at observer 1 meter away from the multiviewer was 106 ft candles with no films on the viewer, 67 ft candles with conventional films filling the viewing board and 46 ft candles with the masked Agfa films filling the viewing board. Thus the masking resulted in a 30% reduction in the ambient light compared to conventional films.

2. Consistency of image optical density in the same patient and among patients. The ADC adjusts the optical density of the final image to fall within preselected limits. It provides greater control of the optical density than does conventional film radiography. The optical densities of 10 matched cases obtained in the book cassette is shown in table 1. While the mean optical densities are almost identical, there is less variability in optical density as shown by the smaller standard deviations seen with SR.

Table 1: Optical density of FR and SR of a group of 10 NICU Patients with images obtained in a book cassette; mean and standard deviation.

Exam type	Lung	Mediastinum
FR	1.04 (0.46)	0.74 (0.33)
SR	1.00 (0.36)	0.72 (0.24)

3. There is an improvement of visualization of the soft tissues in views of the extremities with the ADC system using a special form of processing called "Checkers" This will be demonstrated in the exhibit.

4. The ADC allows for electronic magnification of the image with no increase in patient dose.

5. The ADC allows for immediate and direct entry of the image data into the PACs for transmission to the NICU.

The digital imaging system provides images that are equal to conventional film radiography in the

1. Identification of life support tubes and lines.
2. The identification of abdominal disease.

Disadvantages of the Agfa ADC in Pediatric Radiology:

1. The prototype system is slower than conventional film radiography. It takes approximately 9 minutes to process an image. This delay has resulted in less than complete acceptance of the unit in the NICU. The production model (not yet available in the U.S.) takes 2 1/2 minutes for processing.

2. The current version of the system does not provide as good resolution as conventional film-screen high speed systems. This is visible on NICU films on direct comparison with the conventional comparison radiograph. The resolution of the conventional film screen system used at Georgetown is > 4.8 lp/mm. That of the Agfa imaging plate is > 4.8 lp/mm. The resolution of the Fuji imaging plate is > 4.8 lp/mm. Fuji also produces a higher resolution imaging plate.

Summary:

Clinical tests of the Agfa ADC phosphor storage plate imaging system demonstrate that there are advantages in image quality compared to conventional film radiography except in the area of resolution. The lower resolution of the Agfa plate is considered to interfere with accurate diagnosis in premature infants. Based on the other advantages of the system, the investigators would encourage Agfa to develop a higher resolution plate for clinical use in the NICU.

Acknowledgement:

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Tests of the AGFA ADC Phosphor Plate Imaging System

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The AGFA ADC Phosphor plate imaging system (ADC) is undergoing clinical tests in the Georgetown University Department of Radiology.

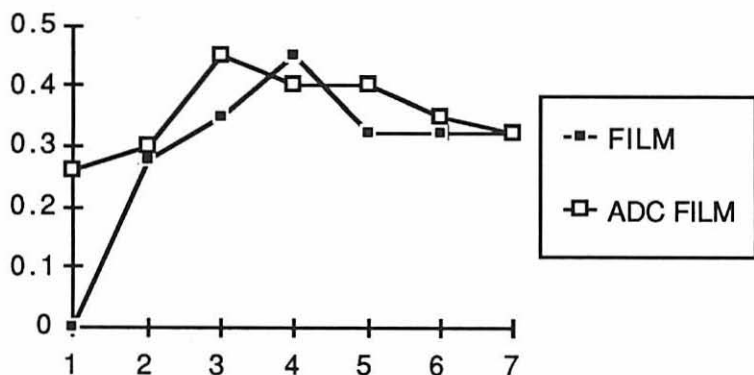
Comparative tests of the consistency of image optical density within and among patients demonstrated that the ADC provides better control of the maximum and minimum film density on the printed image than does conventional film radiography (FR). The Fuji AC-1 (FCR) demonstrated an intermediate level of control as demonstrated in table 1.

Table 1: Optical Density of 16 bedside examinations, Minimal and Maximal Optical Densities:

Film-Screen:	Max O.D.: 2.43, S.D. 0.31;	Min O.D. 0.90, S.D. 0.28
Fuji AC-1:	Max O.D.: 1.36, S.D. 0.25	Min O.D. 0.41, S.D. 0.10
AGFA ADC:	Max O.D.: 1.44, S.D. 0.13;	Min O.D. 0.33 S.D. 0.05

Tests of robustness of diagnostic accuracy as exposure factors change demonstrated that the ADC provides a greater robustness than conventional film-screen radiography. The test was performed in an anthropomorphic phantom using water radiodensity simulated lung nodules. MAS and KVP were varied. Two readers interpreted the images. The results are shown in Graph 1.

Variation of sensitivity as MAS and KVP vary



A test of reader performance on interpretation of intensive care unit chest radiographs was performed comparing good quality conventional portable chest radiographs to simultaneously obtained ADC images. The ROC areas indicated no statistically significant difference between FR and SR interpreted on film and between FR and SR viewed on a Workstation. Three readers participated in each reading experiment. Diagnoses were divided into a group of lung and pleural disease, and a group of mediastinal structures and chest tubes.

Average ROC areas for Lung and Pleural Disease

FR = 0.88; SR printed on film = 0.91

FR = 0.88; SR viewed on Workstation = 0.88

Average ROC areas for Mediastinal structures and chest tubes

FR = 0.98; SR printed on film = 0.96

FR = 0.96; SR viewed on Workstation = 0.93

The ADC is currently in routine daily use at Georgetown for bedside and in-department chest radiographs, abdominal and skeletal examinations.

Demonstrations

Computer Assisted Diagnosis of Musculoskeletal Tumors: Microcomputer-Videodisc Hybrid

*Eric S. Schulze, M.D., Ph.D., Felix S. Chew, M.D.
and Gwilym S. Lodwick, M.D.*

Department of Radiology, Massachusetts General Hospital and Harvard Medical School, Boston, MA

A microcomputer expert system for the radiologic analysis and diagnosis of musculoskeletal tumors was combined with a set of radiologic images on videodisc to make a hybrid teaching platform. The hardware workstation consisted of a Macintosh SE/30 computer (Apple Computer, Cupertino, CA) in tandem with a videodisc player and monitor.

Analog optical disc technology was used to create an image base of approximately 1,000 different images of musculoskeletal lesions, including graphics, radiologic images with and without superimposed graphics, and radiologic images with and without photographic magnification to regions of interest. Images were captured in a dedicated, professional studio and mastered onto a 12-inch CAV format videodisc [1].

A hypertext program was written for the Macintosh computer to coordinate the user, the expert system, and the videodisc image set. The primary goal in designing the computer interface was to make the underlying technology virtually invisible, as the users would not be trying to use the computer *per se*, but rather trying to learn musculoskeletal tumor diagnosis. The interface was written in HyperCard/Hypertext (Claris Corp, Santa Clara, CA), but the actual diagnostic expert system was written in THINK Pascal (Symantec Corp, CA). The expert system was installed in the HyperCard program as an external command and allowed passage of questions and answers back and forth to the interface. The algorithm and diagnostic probability matrices were derived from a study of actual clinical material [2], and a similar program had been previously incarnated in a different digital format [3]. Only bone tumors were included in the probability matrices, and non-neoplastic differential possibilities such as infection and metabolic bone disease are not considered.

The computer program prompts for and accepts clinical information and the student's radiologic analysis of an image, creating after each answer a list of differential diagnostic possibilities, each assigned a probability of being the true diagnosis. Questions include clinical data such as age and sex, and radiologic findings such as the size and location of the lesion, description of the margins of the lesion, the presence or absence of matrix mineralization within the lesion, the presence or absence of cortical penetration, etc. After all questions have been answered, a final diagnostic list and estimation of tumor grade are provided along with commentary regarding further evaluation and management.

The videodisc player, under control of the computer, can display relevant examples of either specific radiologic features or possible diagnoses. The computer proffers the relevant images to the interface where the user can choose them by clicking with the mouse button. The videodisc images are supplemented by diagrams pasted into the computer program. The combination of the videodisc images with the expert system teaches not only the abstract process of diagnosis but also the visual task of recognizing and describing the relevant radiologic features necessary to the process of diagnosis.

The program behaves like an expert diagnostician who has at hand an example to illustrate each question and answer. This hybrid teaching platform has been successful in teaching students to recognize and assess the diagnostic importance of the various clinical and radiologic features of musculoskeletal tumors. It is in use for teaching at the medical student, resident, and practitioner levels.

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2. Lodwick GS. The bones & joints. Chicago: Yearbook Medical Publishers, 1971
3. Lodwick GS. The radiological evaluation of skeletal lesions with computer assistance. Proc Natl Cancer Conf 1970; 6:737-41.

Computer Assisted Interactive Videodisc Teaching Program in Diagnostic Radiology

Felix S. Chew, M.D. and Susan L. Belanich

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The design of educational materials in diagnostic radiology requires coordinating a source of radiologic images with a source of nonvisual information. Such a system to teach musculoskeletal radiology was designed, implemented, and tested using a hardware workstation consisting of a microcomputer and a videodisc player with monitor.

Analog optical disc technology was used to create an image base of approximately 10,000 different images, including graphics, radiologic images with and without superimposed graphics, and radiologic images with and without photographic magnification to regions of interest. Images were captured in a dedicated, professional studio and mastered onto a 12-inch CAV format videodisc. Compared with digital formats, image quality and access speed of the analog system were similar, but storage capacity was superior: the image set would have required nearly 800 Mb for noncompressed digital storage.

A hypertext program was written for the Macintosh computer to present textual and diagrammatic information in an interactive, nonlinear fashion. The primary goal in designing the computer interface was to make the underlying technology virtually invisible [1-2], as the users would not be trying to use the computer *per se*, but rather trying to learn musculoskeletal radiology. The operation of the system was to be as natural as turning a page. By virtue of its visual interface, the Macintosh was found to be the ideal medium for this, and the availability of high-level programming environments such as HyperCard/Hypertalk (Claris Corp, Santa Clara, CA) made it even more attractive for a developer without recent previous programming experience. On the final interface, options are presented on the screen and activated by a click of the mouse button; immediate feedback follows. The keyboard is not used.

Clutter is reduced by showing only those options that are applicable to the user's current position in the program and hiding the others. Visual consistency provides natural mapping between actions and results and assures the user that similar actions will always yield similar results. By the same token, a logical relationship exists between actions on the Macintosh screen and the rendering of images by the videodisc player. Although it actually restricts the user, this environment creates a sense of empowerment over the machine.

The project used existing educational materials. Conversion of 650 teaching file cases and an accompanying 265-page textbook [3] to videodisc format with barcode book [4] required six months; studio time was six weeks. Conversion of a 75,000 word text file with an accompanying directory of image locations on the videodisc to a workable HyperCard stack required three months; testing and creation of the final interface required three more months.

In the evaluation phase, it was noted that once students became accustomed to the speed and smoothness of the system, they were able to focus on the content, operating the computer almost intuitively. Relative to materials such as books, slide-audiotapes, videocassettes, and film teaching files, this computer-videodisc hybrid has the advantages of a large image base with random access, images viewed with transmitted rather than reflected light, compact size, and relatively low cost. Relative to fully digital systems, the players and monitors needed for the end user of the analog videodisc system are economical and readily available. Through the use of barcodes, the videodisc images can be used in conjunction with printed materials for those without computers. Integrated with more traditional methods, this system is in successful use at the medical student, resident, and practitioner levels.

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A Multimedia Multimodality Interactive Tutorial Using Macromind Director 3.0™ For Macintosh™

Huyen D. Tran, Bruce J. Barron, Lamk M. Lamki, Gordon C. Carson, Thomas W. Twiford and E.H. Zuniga

University of Texas Health Science Center at Houston

This is a scientific demonstration of the multimedia computer as a teaching tool. The authors have created a user-friendly multimedia program with extensive interactive capabilities by fully utilizing the features of MacroMind Director 3.0™ for the Macintosh™ computer. The program is a self-guided tutorial on the utility and interpretation of brain imaging using multiple imaging modalities, including High-Resolution Three-Headed Single Photon Emission Computed Tomography (SPECT) with 3-Dimensional Display, High-Resolution Computed Tomography (CT), and High Field Strength Magnetic Resonance Imaging (MRI). Topics covered include normal brain anatomy and the utility of SPECT imaging in various pathological states, e.g., cerebro-vascular disorders, HIV infection, cocaine abuse, cognitive and effective psychiatric disorders, penetrating and closed-head traumatic brain injury, and seizure disorders, with emphasis on correlative imaging. High resolution color images are integrated with animation, a sound track, and synthesized speech for high educational impact. Novices may follow a continuous automated tutorial without touching the computer, while computer-literate users will interact more extensively with the user-friendly program, which has context-sensitive help available on-line. Future potential applications of this program include expanded teaching at all levels, research, and computer-aided interpretation of correlative imaging.

Preparing for PACS Medical Image Compression

Murray G. Baron, M.D. and Doris S. Strange

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Possibly the greatest single problem faced by every PACS is the immense size and number of the data files that must be stored, transmitted and displayed. A single chest film, digitized at $2K \times 2K \times 12$, produces a 6 Mbyte file. This volume of data profoundly influences the functional efficiency as well as the cost of every component of the system. Means for compression of the data files without loss of diagnostic information are critical precursors to the design and implementation of any PACS.

Most of the work on image compression, to date, has dealt with qualitative compression, developing mathematical algorithms to compact the data files that will allow them to be fully reconfigured when needed. Unfortunately, the degree of compression that can be accomplished is limited. If the compression-uncompression cycle is to result in an identical image to the original, compression ratios of no greater than 3 or 4 : 1 can be achieved with analog images, and less with digitally acquired images. A greater degree of compression is possible if some loss of data, usually in the form of a lessened S/N ratio is allowed. It may be possible to attain a compression ratio of 40:1 and still produce a diagnostically acceptable image. This will vary with the resolution of the original image as well as the subject matter.

There is, however, a second type of compression that may yield even greater degrees of file shrinkage without any practical diagnostic loss. Such quantitative, or medical, compression decreases the transmitted data file by selecting only pertinent films to send. Although we routinely shift heavy, overstuffed film folders when a

clinician requests a patient X-rays, it is extremely rare for one physician to review more than a few of the films. Using rules based systems, we feel it is possible to define these selections so that the PACS can choose the proper mix of films to transmit, almost automatically.

The process is accomplished in two stages: selection by the radiologist at the time of interpretation and selection based on the patient's diagnosis, the reason films are being requested and, possibly, the specialty of the requesting physician.

A large number of films can be culled by the radiologist when he reviews the case. It is rare for a multifilm examination to contain critical information on each film. If each film in an examination can be identified, perhaps with a subscript to the accession number, the radiologist can indicate those images he feels are pertinent when he dictates the case. Assuming that the RIS and PACS intercommunicate, a small set of films can be identified that will adequately summarize each examination. Thus, an upper GI series of 7 overheads and 16 spot films may be adequately represented by 2 images, a 90 image CT scan by 4 and so on. Whenever this study is requested or included in a packet to be sent to a workstation, only those images are included. If the entire examination is required for some special reason, or a research project, the requester will have to wait a short period of time while it is retrieved from optical storage.

Most repetitive examinations are compared with at least the last previous examination of that type. If there has been no change in the appearance of the chest since a film made one year earlier, why send both. Similarly if a compressed vertebral body has not changed over twenty years, why send all the intervening examinations. It is likely that a representative image from the first study and a similar image from the current exam will be sufficient.

Access to the admission diagnosis and any acute diagnoses is critical if this method is to work. If a patient is admitted to the ICU with an acute myocardial infarction, why send films of a fractured tibia the patient suffered two

years ago? ON the other hand, if the patient is admitted because of an endocrine disorder, almost all of the previous examinations may be pertinent.

The specialty of the physician, particularly of a consultant may also be of import. The chest physician evaluating the patient because of a pulmonary mass will usually be satisfied with a report of an MR study of the head and will not require the films. Actually, with time, it is conceivable that profiles for individual physicians can be developed. This selection process will probably not apply to the radiologist who is interpreting a new examination as it is difficult to foresee which of the previous images may be needed. For example, fine fibrosis at the base of the lung is often better visualized through the shadow of the liver, on an abdominal film, than it is seen on the chest films.

We have proven the efficacy of medical compression by manually reviewing films and correlating them with case histories. In some instances, a compression ratio exceeding 40:1 is possible. The translation into computer algorithms has just begun. The advantage of the method is that there is absolutely no loss of detail in the included images so that qualitative compression can also be applied, resulting in a very substantial reduction in file size.

Digital Subtraction of Dental Radiographs Using Projective Invariants

John A. Tardy and Stanley M. Dunn

Department of Biomedical Engineering, Rutgers University Piscataway, NJ

The detection and diagnosis of many oral pathologies can be reduced to a problem of detecting changes which occur during the elapsed time between two dental radiographic measurements. Although the radiographs contain all of the available information, the complex structure of the scene often obscures the minute changes which may have occurred. Given these conditions, the technique of digital subtraction can be applied to remove the unwanted background structure and show only those areas which have undergone change. The difficulty in applying this technique as a diagnostic tool lies in the positioning of the patient, the x-ray source, and the film. If the two images are not projections of the same area, then the subtraction results will be unsatisfactory.

The most common solution has been the development of mechanical devices which ensure the reproducibility of the patient's position with respect to both the x-ray source and the film. Research done on subtraction utilizing such mechanical devices has proven that the subtraction technique results in both correct diagnoses [1] and earlier detection of periapical and periodontal lesions [2]. Unfortunately, the custom made mechanical devices used to reproduce the imaging geometry are both uncomfortable for the patient and cumbersome for the practitioner, and therefore the technique has not found wide clinical use.

The fundamental concept of *projective invariants* allows us to perform digital subtraction without mechanical control of the radiograph formation. A projective invariant is a quantity which remains the same for a given object regardless of any projective transformation, i.e. independent of viewing direction. The invariant quantity is calculated using geometric relationships among projections of anatomical features which are visible in both images [3,4]. The selection of feature points which are common to both images establishes a correspondence between the two radiographic projections. Therefore, this correspondence is based on features which are intrinsic to the object, and does not rely on an externally defined coordinate system. Since an external reference is no longer needed, the mechanical constraints on the radiograph formation may be removed.

Since x-rays are transmitted through the object, each point on the radiographic film represents the summation of attenuation coefficients along a ray through the object. The projection of this ray onto the second image plane is called

an *epipolar line*(see Figure 1). Therefore, having established the correspondence between the two radiographs using projective invariants, each point in one image can be transferred to its corresponding epipolar line in the second image. Continuing this process for all points in the image, the standardized view is produced without constraining the image formation geometry. Once the images are standardized, they can be subtracted to show the structural differences between the two. Successful implementation of this technique will offer the dental community a new and powerful tool to aid in radiographic assessment and diagnosis. Extensions to other tomographic image formation systems will also be discussed.

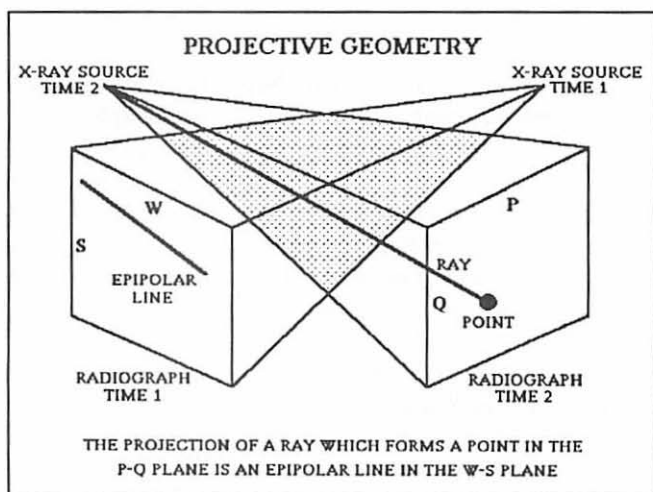


Fig 1.

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High Resolution Display Systems for Medical Imaging

Dr. Sanford Rabushka

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Steven Trombetta

Advanced Video Products, Littleton, MA

Despite the many benefits associated with digital imaging technologies, the adoption of non-film media for medical imaging has been slowed by two main factors: insufficient screen resolution to permit reliable viewing of many images and insufficient performance to provide an interactive environment.

Advanced Video Products has designed a display workstation which addresses the image quality needs of the medical community by providing 2048 x 2560 pixel resolution and 12 bit (4096 gray shades) contrast resolution - the highest resolution monitor available. The display monitor has been the subject of several studies and is now in its third generation design. The result is a viewing environment with film-like imagery. The display features a 72 Hz non-interlaced refresh rate, P104 phosphor, and 60 footLamberts brilliance.

The AVP MegaScan display controller contains a multiple memory architecture designed to preserve the 12-bit data and yet, provide fast image loading, image viewing, and image enhancement performance in a computer network configuration.

728 bed Christian Hospital Northeast-Northwest is the flagship facility of the Christian Health System, a regional healthcare delivery system in Missouri and Illinois. Films, CT, and MR images are digitized on-site, as well as in two satellite hospitals. The images are transmitted via T-1 and ISDN phone lines and over a local area network to Radiology where they are read on a dual monitor, 2048x2560 display station.

Dr. Rabushka and Mr. Trombetta will share their clinical and technical knowledge of viewing medical images on these unique monitors. Image processing techniques will be performed on a variety of images and Christian Hospital's network for digital image management will be discussed.

Teleradiology: A Powerful, Functional AND Affordable Solution

Jeffrey S. Siegel

Evergreen Technologies, Inc., Gaithersburg, MD

Introduction

Teleradiology has been a topic extensively discussed by the press and trade journals for many years, yet few institutions make use of the capability. The ability to transfer medical images across town or around the world can provide better, more cost effective medical care. Expertise and new knowledge can be shared, lowering the total cost of providing high quality health care to more individuals. New enabling technologies, such as fast high-quality modems and more powerful personal computers have made this capability possible on the physician's desktop. The question arises: Why haven't these systems proliferated to more hospitals, research labs, and physician's desks?

To date, these systems have been expensive, highly custom configurations which have required large amounts of support and have been difficult to use. Further, these systems have typically been little more than high quality fax machines which simply scan film or capture a video picture, and send a static image. Additionally, they often require invasive hardware devices. The data which result from these methods are merely a picture of the original data. Without the original data from the CT, MR or other medical device, a physician is prevented from performing detailed analysis or controlling data visibility.

Evergreen Technologies recently installed a teleradiology system between a military hospital in the United States and a hospital in the Middle East using only standard hardware and commercially available software. The system was configured using Macintosh™ personal computers, standard communications software and MedVision™ medical imaging software to view and analyze the data. The MedVision software was chosen because it enables the physician to receive the full data set produced by the medical device giving them complete control over the data received, while costing only \$895. Standard personal computers and peripherals were used to provide the most cost effective hardware solution, to allow for simple, inexpensive upgrades, and to minimize technical support.

System Description

The system designed used two Apple Macintosh IIx personal computers for the capturing, viewing, and enhancing of images. The system in the Middle East additionally consisted of a X-ray scanner from Truvel used for the occasional capture of film, and video input which allowed the capturing of images from a video camera and a microscope. The system in the U.S. was designed for image viewing only.

An IBM PS/2 PC was used at each site to act as a telecommunications bridge to transfer images and other data files. The PC was attached to the Macintosh computer via a local area network. The separate PC was used to remove the telecommunications workload from the Macintosh and to provide a reliable batch transmission capability

which allowed for both overnight and urgent, immediate transfer of data. The communication system incorporated special security features which permitted transmission of data between known computers only.

The system was designed to be easy to use. This was accomplished by taking advantage of the inherent user friendly aspects of the Macintosh and MedVision's user interfaces. Special one-button function keys were programmed on the PC to allow for simply immediate file transfer.

By using standard hardware and software components, a system which was functional, affordable, and easily expandable was created. New hardware components can be substituted to provide faster processors or accommodate new technologies. MedVision's modular design allows new capabilities to be added or enhanced within the same software package. This flexibility permits new functionality within the package, such as *teleconsulting*, the interactive communication between physicians which allows for increased levels of consultation between medical organizations around the world.

Application Description

The system is being used to transmit medical images pertaining to a single, critical patient in the Middle East to doctors in the U.S. for ongoing consultation. It was designed to be utilized by personnel who are unfamiliar with computer usage; therefore, it was critical that all interfaces be simple to use. This was accomplished primarily through the utilization of the intuitive interface of the Macintosh and MedVision's simple to use imaging tools.

A variety of medical images including CT, X-ray, and video are being transmitted from the Middle East to the U.S. for interpretation. The end user required that relevant images captured that day be transmitted via a batch process every night for interpretation by physicians in the U.S. Additionally, they required the ability to send an image immediately at any time of the day or night should an emergency situation occur. This capability was made simple through the use of preprogrammed function keys which enabled a user to simply press a button for immediate transfer to occur.

MedVision was utilized to enhance the viewing and analysis of the images for the medical professionals at both sites. MedVision's capacity to access the full 16-bit data generated by the medical devices allows the physician to measure and analyze these images accurately. The tools provided have been designed specifically to meet the requirements of medical image analysis and manipulation, allowing users to quickly begin making critical interpretations. Its modular environment provides a system which is expandable. new capabilities can be added by acquiring new software modules from Evergreen, or by using the Developers Toolkit to create your own software modules.

Conclusions

By selecting only standard, off-the-shelf software and hardware components, Evergreen was able to create an affordable, flexible, highly extendible system. The solution was brought on-line quickly due to the usage of these proven technologies. Finally, the system allows for continued enhancements as the standard hardware components can be upgraded with newer components without disrupting the system or requiring complicated integration. The MedVision software allows new modules to be added to the environment to provide new capabilities, or to simply enhance or modify existing ones.

Realistic Three-Dimensional Visualization of Joint Surfaces and Soft Tissue From CT Data

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Kansas City, MO

Our purpose is to perform accurate and realistic non-invasive "dissection" of human anatomic structures. These structures include bones, joints, tendons, ligaments, nerves, veins and arteries.

A Pixar computer work station and CT data are used to render three-dimensional images of various anatomic structures. Improved CT data is obtained by reducing patient movement, proper maintenance and calibration of CT, and proper techniques. Software tools are used to analyze CT data, find structure edge voxels, do data subtractions of structures, etc. Displays furnished to the ordering physician may include any or all of the following: a spinning or rocking of views about any of the X,Y, or Z axes from the computer display monitor or VHS videotape; photographs of selected views to preserve the high image quality, as opposed to VHS; still stereoscopic views of selected images to preserve depth perception.

3D-CT has been performed on various aspects of the anatomy. Even with the limitations imposed upon 3D-CT images by spatial and contrast resolution, the fidelity of many 3D-CT images mimics anatomic photography (Figure 1). This is achieved by careful attention to structure edge interpolation, shading and colorization parameters. Semi-automated edge detection software enables data subtraction of bones adjacent to articular surfaces. 3D-CT volumetric 'data-disarticulation' allows an unique opportunity to view joint surfaces previously seen only at open dissection. No other imaging method provides a direct end-on view of articular surfaces. Depressed tibia plateau fractures may be easier to appreciate when compared to data-reversed 3D-CT volumetric reconstructed images of the normal knee. This technique of directly comparing the mirror image of the normal anatomy to the abnormal anatomy is useful in some cases. Soft tissue surfaces can be depicted in three dimensions, as well (Figure 2). While color and shading are partly a matter of esthetics, many physicians prefer images shaded in realistic anatomy colors.

This visualization assists in the diagnosis and surgical planning for complex injuries and contributes to more informed patient management decisions. Surgeons report that accurate visualization of joint surfaces reduces the time in the operating room, reduces hospital stay, reduces radiographic exposure, and fosters learning for residents. Partial success has been achieved in the visualization of soft tissue structures. Additional development is planned to increase the yield of diagnostic image information.

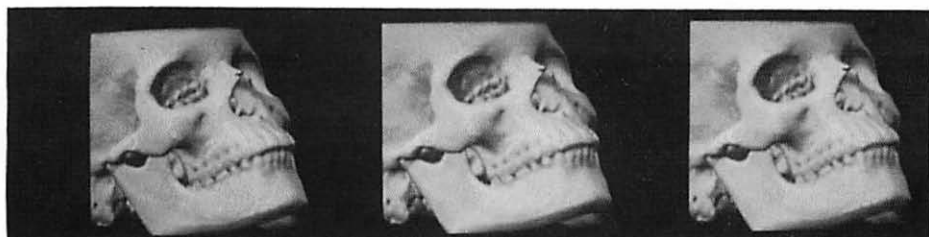


Figure 1. Photorealistic Rendering from CT Data

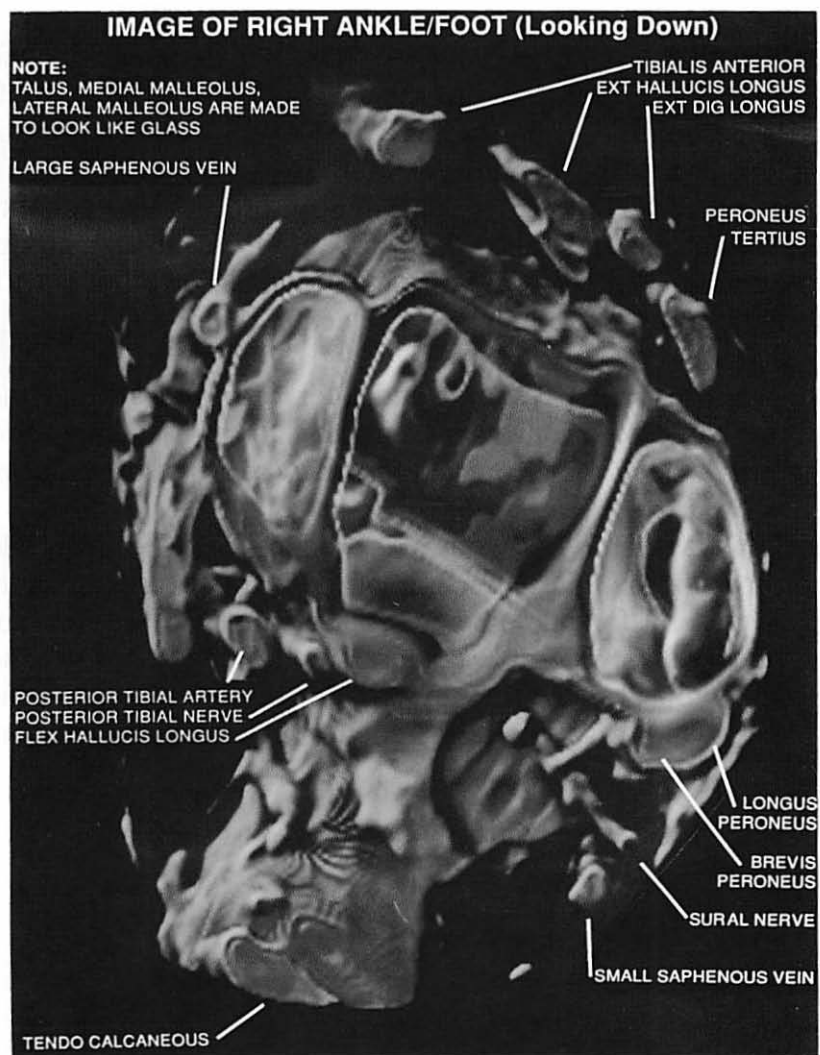


Figure 2. Rendering of Soft Tissue from CT Data

DICOM-SHOW ©

A demonstration software which explains and demonstrates the assembly of data according to the ACR-NEMA DICOM draft 3.0. Based on an object-oriented WINDOWS 3.0 © program it permits hands-on experimentation with different input structures. The interactive data entry process is modality specific, thus facilitating the data entry of the acquisition group. All enumerated options are displayed in pull-down boxes with automatic transfer of the chosen selection.

Group entries can be stored and later retrieved so that the operator can design convenient templates for re-use. Only a few field entries need to be changed for a new series of procedures.

The DICOM-SHOW © software produces the header code according to the latest version of DICOM. This capability makes it useful for implementers of the standard, who do not wish to spend considerable resources on writing software. The software will also be of interest to sales and marketing managers who wish to gain a better understanding of the DICOM data structures.

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ADDENDUM

Papers not received in time for publication

SESSION 1.

Does Radiology Really Need PACS?

Bernd Kohlberger, Radiologische Klinik, Universitätsklinik
Freiburg, Freiburg, Germany

First Clinical Experiences of a Fully Digital Hospital: The Vienna SMZO Danube Hospital

Hans Mosser, **Michael Urban**, and **Walter Hruby**, Department of
Radiology, SMZO Danube Hospital, Vienna, Austria
W. Rueger, Siemens Medical Group, Erlangen, Germany

SESSION 2.

Dan Maloney

SESSION 3.

Accuracy and Reproducibility of Area Measurements Using a Semiautomated Image Analysis System

Christian J. Herold, **Robert H. Brown**, **Jonathan M. Links**,
Elias A. Zerhouni, The Johns Hopkins Medical Institutions,
Baltimore, MD

Recognition of the 3D Location of Biomedical Structures Based on a 3D Analysis of X-rays 2D Images

Lionel Brunie, **S. Lavallee**, and **B. Mazier**, Laboratoire d'Informatique
Medicale, La Tronche, France

Recognizing and Locating Higher-Dimensional Objects

H. Gerst, **K. Richter**, **K. Kaiser**, **B. Lemke**, **W. Steinbach**, and
G. Strahmel, Institut für Herz-Kreislaufforschung, Berlin, Germany

SESSION 4.

Medical Effectiveness: Automated Data and Data Standards

J. Michael Fitzmaurice, Office of Science and Data Development,
Agency for Health Care Policy and Research, Rockville, MD

SESSION 5.

Quality Assurance in Serial Chest Radiographs

Irena Tocino, Department of Radiology, Yale University, New Haven, CT

SESSION 7.

Dual Lookup Table Algorithm for Displaying 16-bit Images on Image Display Workstations with 8-bit Video Systems

Thurman Gillespy, III and *Alan Rowberg*, Department of Radiology, University of Washington, Seattle, WA

Evaluation of X-ray Film Digitizers

Thomas Lane and *Robert Murray*, University of Texas Southwestern Medical Center, Dallas, Texas

SESSION 8.

Processing and Analyzing for Decision Making on Health Care of Population Exposed to Radiation Following the Chernobyl Power Plant Accident

Viktor K. Ivanov, *O.E. Stadnik*, and *O.V. Rozhkov*, Department of Applied Mathematics, Res. Institute of Medical Radiology, Obinsk, Russian Federation

SESSION 9.

A Personal PACS for Orthopaedic Surgery

R. Larry Dooley, Bioengineering Department, Clemson University, Clemson, SC

Christian Engel and *Maurice E. Muller*, Maurice E. Muller Foundation, Berne, Switzerland

Planning for the Progressive Introduction of Radiology Global PACS

Arthur Naylor, A.F. Naylor Company, Cleveland, OH

SESSION 10.

First Experiences with VoiceRad in Daily Practice

K.H. Schuur and *L.E.H. Lampmann*, Department of Diagnostic Radiology, St. Elisabeth Ziekenhuis, The Netherlands

SESSION 12.

Integration of Hospital, Radiology and Other Departmental Information Systems with PACS: The Requirements of the Radiologist

Hans Mosser, Michael Urban, and Walter Hruby, Department of Radiology, SMZO Danube Hospital, Vienna, Austria

SESSION 13.

Advanced Radiologist Support in Skeletal Radiology

Christian Gartner, S. Nissen-Meyer, J. Weber, P. Kohz, Thomas Hilbertz, and U. Fink, Department of Radiology, Klinikum Grosshadern Marchioninstr, Munchen 70, Germany

SESSION 14.

Radiology Information Systems in 1992

Roger A. Bauman, Department of Radiology, Massachusetts General Hospital, Boston, MA

Using a Macintosh Database and Bar Code Reader for Continuous Quality Assurance of Radiographic Film Quality

Thurman Gillespy, III, Michael L. Richardson, Michael Alotis, and Stephen Marglin, Department of Radiology, University of Washington, Seattle, WA

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Elements Required for the Construction of a Reliable PACS Cost Model

John G. Robertson, Department of Electrical Engineering, University of Ottawa, Ontario, Canada

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Bruno Bagni, Department of Nuclear Medicine, South Anna Hospital of Ferrara, Ferrara, Italy

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Alan H. Rowberg, Department of Radiology, University of Washington Medical Center, Seattle, WA

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Donald V. Smith, Department of Radiology, Madigan Army Medical Center, Tacoma, WA

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Monet R. Sheehy and **Robert E. Detreville**, MDIS Project Office, Frederick, MD

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